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1. Thurston. Work of the U. S. Board appoint
Test Metals. 1878.

2. " . A New Method of Detecting Over
in Metals. 1878.

3. Nystrom. Elements of Mechanics. (specimen p

4. Hunt. The Method of Testing Steam

Wood. Triangular Beams.

. The Holly System of Steam Heating. 18

Powell. Methods of Surveying the Pu
Domain. 1878.

Chevandier. Les Propriétés Mécaniq
Bois. 1848.

Thurston. The Mechanical Engineer. 1

Lewis. Preservation of Wood.

Egleston Investigations on Iron &
Steel Rails. 1877.

8½. Thurston. A New Type of Steam
Engine. 1877.

ABSTRACT OF STATEMENT

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OF THE

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Test Iron, Steel, and other Metals.

BY

ROBERT H. THURSTON,
OF HOBOKEN, N. J.

From the Proceedings of the American Association for the Advancement of Science,
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ABSTRACT OF STATEMENT OF THE EXTENT AND CHARACTER OF THE WORK OF THE UNITED STATES BOARD APPOINTED TO TEST IRON, STEEL, AND OTHER METALS. By ROBERT H. THURSTON, of Hoboken, N. J.

THIS Board was appointed by the President of the United States, in accordance with the provisions of Section 4, of "An Act making Appropriations for Sundry Civil Expenses of the Government, for the fiscal year ending June 30th, 1876, and for other purposes," approved March 3d, 1875.

It is instructed to determine by actual tests the strength and value of all kinds of iron, steel and other metals which may be submitted to it, or by it procured, and to prepare tables which will exhibit the strength and value of such materials for constructive purposes.

The Board consists of the following named members: —

President— Lt. Col. T. T. S. Laidley, U. S. A.; Commander L. A. Beardslee, U. S. N.; Lt. Col. Q. A. Gillmore, U. S. A.; Chief Engineer David Smith, U. S. N.; W. Sooy Smith, C. E.; A. L. Holley, C. E.; R. H. Thurston, A. M., C. E., *Secretary*.

The Board organized under the General Order issued by the President immediately after the passage of the law creating it, meeting at Watertown, Mass., in April, 1875. The Board at once proceeded to plan an exceedingly comprehensive scheme of work, entrusting each investigation to a Committee — usually consisting of three members — and distributed the greater part of the amount allowed by Congress "for the expenses of the Board," among these Committees, for use in defraying the cost of making researches.

These Committees were:—

(A) On Abrasion and Wear. *Instructions:*—To examine and report upon the abrasion and wear of railway wheels, axles, rails and other materials, under the conditions of actual use.

(B) On Armor Plate. *Instructions:*—To make tests of Armor Plate, and to collect data derived from experiments already made to determine the characteristics of metal suitable for such use.

(C) On Chemical Research. *Instructions:*—To plan and conduct investigations of the mutual relations of the chemical and mechanical properties of metals.

(D) On Chains and Wire Ropes. *Instructions:*—To determine the character of iron best adapted for chain cables, the best form and proportions of link, and the qualities of metal used in the manufacture of iron and steel wire rope.

(E) On Corrosion of Metals. *Instructions:*—To investigate the subject of the corrosion of metals under the conditions of actual use.

(F) On the Effects of Temperature. *Instructions:*—To investigate the effects of variations of temperature upon the strength and other qualities of iron, steel and other metals.

(G) On Girders and Columns. *Instructions:*—To arrange and conduct experiments to determine the laws of resistance of beams, girders and columns to change of form and to fracture.

(H) On Iron, Malleable. *Instructions:*—To examine and report upon the mechanical and physical proportions of wrought Iron.

(I) On Iron, Cast. *Instructions:*—To consider and report upon the mechanical and physical properties of cast iron.

(J) On Metallic Alloys. *Instructions:*—To assume charge of a series of experiments on the characteristics of alloys, and an investigation of the laws of combination.

(K) On Orthogonal Simultaneous Strains. *Instructions:*—To plan and conduct a series of experiments on simultaneous orthogonal strains, with a view to the determination of laws.

(L) On Physical Phenomena. *Instructions:*—To make a special investigation of the physical phenomena accompanying the distortion and rupture of materials.

(M) On Re-heating and Re-rolling. *Instructions:*—To observe and to experiment upon the effects of re-heating, re-rolling, or otherwise re-working; of hammering, as compared with rolling, and of annealing the metals.

(N) On Steels Produced by Modern Processes. *Instructions:*—To investigate the constitution and characteristics of steels made by the Bessemer, open hearth, and other modern methods.

(O) On Steels for Tools. *Instructions:*—To determine the constitution and characteristics, and the special adaptations of steels used for tools.

The above named Committees of the Board were appointed to conduct the several investigations, and the special researches assigned them, in the interval during which the regular work of the Board was delayed by the preparation of the necessary testing machinery, and during such periods of leisure as might afterward occur.

These investigations were expected to be made with critical and scientific accuracy, and were, therefore, to consist of the minute analysis of a somewhat limited number of specimens and the precise determination of mechanical and physical properties, with a view to the detection and enunciation of the laws connecting them with the phenomena of resistance to flexure, distortion and rupture.

The Board proposed to enter upon a more general investigation, testing such specimens as might be forwarded to the President of the Board, or such as it might be determined to purchase in open market, immediately upon the completion of the apparatus ordered, at which time circulars were to be published giving detailed instructions relative to the preparation of specimens for test, and stating minutely the information demanded previous to their acceptance.

At a succeeding meeting, the Board considered applications from manufacturers requesting that work should be done for individual benefit, and passed the following as indicating their views and intentions in this matter.

Whereas, This Board propose, as soon as practicable, to give metal-makers the benefit of its testing machines, and of a skilled experimenter, at a reasonable charge, as a means by which they may give publicity to the behavior of their metals under test; it is

Resolved, That this Board decline to publish the names of metal makers in connection with the experiments certified to by the Board.

Resolved, That this resolution is not to be construed as a refusal to acknowledge contributions of metals and other aid from makers; on the contrary, such services will be always gratefully and publicly acknowledged.

No work of this character has yet been done as the testing machine will not be erected and used until an appropriation for its use is made by Congress.

Immediately upon the completion of the organization and the assignment of researches to the Committees, these committees determined upon the details of their several schemes of work, and the President of the Board, under his instructions, made a contract for a testing machine of a capacity of 400 tons in tension and compression, and sufficiently large to take in columns, or rods, 30 feet long. Of the $75,000 appropriated by Congress, over $50,000 was expended on this testing machine, its foundations, the building in which it was enclosed, a steam engine and boiler to furnish power, and the cranes and other attachments to the machine.

The remainder was distributed to the Committees, and was expended by them and in defraying the travelling expenses of the Board.

The Committees sent out circulars asking assistance and coöperation from manufacturers, and from men of science, of the character of which the following will give a good idea, as well as of the nature of the information sought by the Board.

The Committee on Abrasion and Wear desired to receive from any reliable source such precise data and such information as might enable the Secretary to compile, in as concise and exact form as possible, a statement of the mode of deformation, the rapidity of abrasion, and the laws governing wear in any important typical or exceptional cases.

The executive officers of all lines of railway, might, it was suggested, render valuable aid by furnishing statements of the wear of rails per ton of transportation, specifying with care the original weight, the make, and the character of the rail, the total amount of transportation, the length of time occupied, and stating whether the rail finally broke or was removed. Specimens of rails remarkable either for endurance or for a lack of this quality, if sent to the Committee, would be useful by assisting in the determination of the chemical and other properties which most affect the value of the material under the stated conditions of use. Similar statistics and information in regard to the wear of wheels, axles and other parts of rolling stock and machinery, were said to be equally valuable. Engineers having in any instance noted and accurately recorded such data, were requested to transmit to the Committee copies of their memoranda.

The wear of journals under heavy loads, or at high velocities, as well as under ordinary conditions, is an important branch of the subject. When possible it was desired that the dimensions of the journal, the maximum, the minimum and the mean weight sustained, and the velocity of rubbing or number of revolutions per minute should be given. The nature of the lubricant is an essential element; and its composition, the method and frequency of application and the quantity used, and the coefficient of friction were asked, as also whether heating occurs, and the circumstances of pressure and velocity of rubbing surfaces. Peculiar instances of the behavior, or unusual expedients in the management, of bearings, if described accurately and concisely, were requested.

The wear of tools, under the various conditions of workshop practice, was another subject of investigation. Weighing the tools carefully before and after use, and weighing the amount of metal removed were considered the most accurate method of determining the rate of abrasion. The area of surface finished, and the area of the surface cut by the tool, rate of feed, etc., were to be accurately ascertained and stated. The description of the tool, its shape, method of operation, the kind of metal used in the tool, the temper adopted, the character of the metal cut by it, the velocity of the tool, and, where peculiarities of behavior were noted, a careful statement of them, were desired.

The power required to drive the tool can sometimes be readily determined, and such information was asked as being of great value.

The recent investigations of M. Tresca—*Memoire Sur le Rabotage des Metaux*, etc.—was referred to as an excellent example of such research.

The Committee on Chemical Research announced their intention of making a series of determinations of the effects of carbon, phosphorous, silicon, manganese and other elements, upon the strength, toughness, elasticity and other qualities of iron and steel. The specimens were to be analyzed and subjected to tension, torsion, compression and other mechanical tests.

Makers of metal were requested to give a full description of the kind and make of raw materials, and of processes employed in the manufacture of the bars, and also of the size of the ingot or pile, the number of re-heats, and the extent to which hammering or rolling was employed in the reduction, to be kept in a reference book—each description having a number corresponding with that of the bar—all of which would be of great value.

Analyses, including color carbon tests—in case they had made them—were to be given in the above description, together with their mechanical tests of the material furnished, with statement of shape and dimensions of specimens tested, were all to be recorded and furnished.

This Committee requested each maker to supply, where possible, one or all of the grades of steel in the following list: —

1 bar of Steel, containing	. . . .	0.10 per ct. carbon.
1 " " "	. . . .	0.20 " "
1 " " "	. . . .	0.30 " "
1 " " "	. . . .	0.40 " "
1 " " "	. . . .	0.50 " "
1 " " "	. . . .	0.60 " "
1 " " "	. . . .	0.70 " "
1 " " "	. . . .	0.80 " "
1 " " "	. . . .	0.90 " "
1 " " "	. . . .	1.00 " "

The Committee also asked: —

1 bar of each of such irons or steels as may show any particularly good or particularly bad qualities, or such as may exhibit any very marked or unusual characteristics.
1 bar of best wrought iron, with its trade mark stamped upon it.
1 bar of very hard, but not cold short wrought iron.
1 bar of extremely soft wrought iron.
1 bar of average "puddled steel."

It was further proposed to test series of steels in which one element, as phosphorous, manganese or sulphur, varied by tenths or other fractions of a per cent., all other elements being as nearly as possible constant in amount in each series.

The Committee requested to be sent: —

Iron and steel bars of *every variety of temper and quality.*

It seemed (they stated,) important to ascertain what chemical constituents, and how much of them, make iron *bad*, as well as good; and what elements give it any peculiarities. The Committee were, therefore, quite as anxious to get bars of bad, and especially of peculiar qualities, as to get standard specimens. Neither the chemists nor the experimenters were to know who made the bars submitted to this series of tests, and no names will be published in connection with the report on results of test.

A full description was required of the kind and make of raw materials, and of processes employed in the manufacture of the bars, and also of the size of the ingot, or pile, the number of re-heats, and the extent to which hammering or rolling were employed in the reduction, each description having a number corresponding with that of the bar.

The Committee appointed to determine the effects of variation of temperature upon the metals, proposed to ascertain facts relating to the behavior of rails and of machinery exposed to the extremes of temperature observed in northern latitudes, which, where exposed to wear or to breakage, afford valuable data. The character of the fracture and the texture of the abraded surfaces, as well as the statistics ordinarily collected, were to be noted. Specimens exhibiting peculiarities of behavior or appearance, and photographs of masses which it may not be convenient to forward, were asked as of real value. Where exact quantitative analyses of metals exhibiting unusual characteristics could be given, they were requested as aiding effectively in the determination of the causes of such peculiarities.

The statistics of well-managed railroads were expected to afford useful and reliable information. Rolling mills, producing rails and other forms of rolled iron which are tested by the drop, it was thought might be able to furnish more accurate statements of the effect of changes of temperature in modifying resistance to shocks.

Some experimental work had already been done in this field, and it was desired that the results of such researches should be communicated in as great detail and with as much accuracy as possible. Published monographs, references to papers published in scientific, engineering or other periodicals, and unpublished papers, were accepted as valuable contributions.

Assistance was asked by the Committee in the endeavor to ascertain the character of the changes of the force of cohesion produced in the metals and their alloys by variations of temperature, to determine the mathematical expression of the law governing such changes, and to obtain such formulas, either exact or approximate, as would make these results conveniently and practically available to engineers and constructors.

Many experiments have been made by the rolling-mills engaged in the manufacture of wrought-iron beams, the results of which have doubtless been carefully recorded and tabulated. The Committee on Beams and Girders asked copies of such records and tables. Engineers, architects and manufacturers, have also made many experiments upon cast-iron beams and riveted wrought-iron struts and girders, the results of which were requested by the Committee.

It was considered desirable that information as full as might be obtainable, with reference to the constitution and manufacture of the iron used in making the pieces tested, should accompany reports of experiments, especially chemical analyses of the metal where these have been carefully made.

The proportions of the various parts of the samples tested were to be exactly given; and in all riveted work the size and position of the rivets should be clearly set forth. In all cases the modes of applying and measuring the strains were to be stated.

Accurate cross-sections of the samples tested, drawn to scale, large enough to admit of reliable measurements, were desired as greatly facilitating a proper understanding and analysis of the results.

While the machinery ordered by the Board was in course of construction the Committee desired to collect information as above, and to make such experiments as seem practicable by the use of dead loads. For these experiments, and for those which were to be made when the machinery was ready for use, manufacturers were asked to supply such beams, girders and columns as they desired to have carefully and impartially tested.

The Committee on Cast Iron sought information relative to:—

First.—The strength of cast iron—tensile, compressive, transverse, shearing and torsional—under various conditions of quality, form and mode of application; phenomena of rupture; the forms of breakage occurring sufficiently often to suggest characteristic resistances; facts in regard to "steady strain and impact;" the "fatigue" of cast iron from long continued loads and strains, and from frequently repeated vibrations, shocks or blows; practical methods of casting large, bulky masses or very small patterns; methods of making castings intended to resist strains, so as to secure freedom from sponginess and blow-holes; points to be observed in selecting one or more varieties of iron, with a view of attaining definite qualities of castings; methods for discovering imperfections in castings, etc.

Second.—Influence of heat, and of slow or rapid and sudden cooling; chill hardening; refining; crystallographic forms; physical or graphitoidal mixtures of carbon; presence of silicon; effects resulting from changes in the arrangement of molecules from any cause; molecular tension affected by chemical changes; corroding influences when in continued contact with fresh or salt water, or gases; appearances leading to a definite knowledge of quality or character, etc., etc.

The Committee on the strength, etc., of metallic alloys, endeavored to obtain records of all experiments which have hitherto been made in that direction, and to secure such exact information as might assist in further researches.

It was stated as desirable that such records should embody a statement of the precise chemical constitution of each alloy examined, as obtained both by synthesis and subsequent analysis. Its specific gravity, specific heat, conductivity, its combining number, and the relation of its chemical constitution to the series of similar compounds produced by alloying the elements in the proportions of chemical equivalents, were to be stated whenever possible. A few thoroughly well studied examples were said to be of more service than a large number of isolated determinations of single facts.

It was further desired that the ultimate strength, the elastic limit, the modulus of elasticity, the ductility, resilience, homogeneousness, hardness and other mechanical properties of the specimen should be ascertained and accurately stated.

Where only a part of this work could be done by the investigator, the Committee assumed charge of the remaining portion of the research, when the alloy could be furnished in proper quantity and form.

References to published accounts of similar works and monographs on any branch of the subject were asked.

The Departments of Physics and of Chemistry in the various colleges and universities might probably be able to render valuable aid, and their coöperation was earnestly requested.

The Schools of Engineering are in a position to assist this Committee very effectively, and their contributions were gladly accepted.

Specimens of alloys for test by the Committee were to be accompanied by a statement upon proper blanks of their precise constitution, and such information as it might be possible to give, with an account of peculiarities known to distinguish the alloy, and of the special object supposed to be attainable by the investigation.

Where possible, it was required that one or more specimens should be furnished of each of the specified kinds, and of a definite form and dimensions, which were given on application.

Other committees set about their work in a similar way, and the Board thus inaugurated a scheme for the investigation of the strength and physical characteristics of the "useful" metals which was more comprehensive and more thoroughly organized than any ever before attempted.

The Board received very little information from any class to whom the above described applications were addressed.

Some valuable communications were, however, received, and the Secretary has translated a number of papers received from France and Germany, and containing valuable matter, which papers will be printed, should Congress so direct, with the reports of the Board.

Several committees at once entered upon the most important of the investigations ordered by the Board and have continued their work up to the present time. Other committees decided to await the completion of the great testing machine ordered before beginning the heavier work assigned them. In one or two other cases, committees began working, but ceased when it seemed probable that Congress would not sustain the Board in its work, and when appropriations were refused by the House Committee.

In several cases, the want of funds has not prevented good work being done, however.

The Bureau of Equipment of the Navy Department permitted the committees on wrought iron and on chain cables to do their work on the testing machine at the Washington Navy Yard, and allowed those committees to make use of an extremely valuable, very extended and quite expensive, series of tests there made for that Bureau, thus placing in the hands of the Board invaluable material from which to deduce most important facts and principles.

When it seemed probable that the interruption of the operations of one of the most important committees must occur, in the absence of congressional support, private business firms volunteered to furnish the material needed for their work, although the expense was certain to be considerable; and when the preparation of a report was likely to be interrupted in consequence of lack of funds needed in making the calculations, the drawings and the diagrams required to illustrate it, a gentleman whose appreciation of its value was evidently greater than that exhibited by our representatives in Congress offered to pay the cost.

The work done to date may be summarized, as reported by a Committee of the American Society of Civil Engineers as follows: —

> The general plan is announced, and is to be a thoroughly scientific and systematic exploration of the field assigned to the Board. Materials are not only to be tested and the results stated as those derived from the examination of a metal of a conventional denomination, but the test-piece, in each case, will usually be examined to determine how far peculiar qualities are attributable to peculiarities of chemical composition and of physical structure.
>
> A chemical laboratory has been established at Watertown Arsenal, and the chemist to the Board, Mr. Andrew A. Blair, formerly of St. Louis, has already done a large amount of work upon irons, steels and other metals and alloys, and the specimens thus examined as to composition are subjected to several kinds of mechanical stress to discover the effect of the composition in determining resistances to distortion and rupture.

A series of steels is in preparation under the direction of the Committee on Chemical Research, in which other elements being retained constant in amount, the carbon varies regularly from 0 to 2 per cent; another series, with carbon uniform, has silicon in varying proportions; another set varies in phosphorous, still another in sulphur, and another series is variable in manganese. In each series, one element varies between wide limits, while the other elements are all retained as uniform as possible. The work of the melter is checked by analysis, and the specimens are then tested mechanically. This investigation, greatly as it has been needed, has never before been even attempted. It is considered by the members of the Board as likely to prove the most valuable research ever made in this direction, and the only one in which the chemist and the engineer have ever systematically joined forces in making such an exhaustive and scientific investigation.

The Committee on Abrasion and Wear is engaged in collating information relating to this subject, and is making experiments at the Stevens Institute of Technology on the abrasion and wear of the metals, and on the effect of lubrication in reducing it. The Chairman is fitting up machinery and apparatus for use in further investigation. A considerable amount of work has been done.

The Committee on Armor Plate is engaged in collating from domestic and foreign sources information that may be valuable in determining the qualities requisite in armor plate, and how those qualities are to be secured. The records of the Army and Navy Departments, and of the British Admiralty are considered to be the most promising mines of information to be worked by this Committee.

The Committee on Chemical Research has charge of the chemical work referred to.

The Committee on Chains and Wire Rope is endeavoring to determine the character of metal best adapted to making chain and rope, and the proper form and proportion of link, and is working up the data which have long been collecting at the Navy Department. The later experiments of Com. Beardslee are extensive in range, and that officer is collating and arranging the records for the use of the Board. Further experiments will fill up any hiatus that may be detected. The Navy Yard at Washington, where this work is going on, affords peculiar facilities not only for testing, but for making chain cable of any desired size, form of link or quality of metal.

Work already done there by the Chairman of this Committee has revealed serious defects in accepted tables of sizes and strength, and has indicated the rate of variation of strength, with variation of size of bar, and permitted the formation of a new and trustworthy table.

The Committee on the Corrosion of Metals is investigating the conditions affecting the corrosion of metals in use. Some information has been collected, some chemical work has been done, and much more work is projected for the ensuing year.

The Committee on the Effects of Temperature has planned an extended investigation of this subject, and is gathering information from various sources. The research will be commenced by the Chairman during the coming year, if the Board is sustained in its work. The Chairman has already collated all published information accessible in periodical literature,—has made some preliminary experiments, and is receiving some information from various directions.

The Committee on Girders and Columns has a plan of operations which includes elaborate investigations of the strength of materials in columns and girders of various forms and proportions. This is the most formidable and expensive of the researches to be undertaken by the Board, and the power and accuracy of the 400 tons testing machine will be fully taxed in this work. The Committee is receiving the coöperation and active aid of some of the largest manufacturers of beams and girders in the country. The results of experiments already made have been communicated to the Committee by the engineers of railroads and of mills, and in other cases important and costly experiments have been undertaken by private incorporated companies (the Board has been invited to be present and to assist in the work if it should seem desirable); these results are to be given the Board, such sizes and proportions as the Board may desire to test are to be made, and all necessary labor furnished without any expense to the government. Bridge builders, civil and mechanical engineers and architects are corresponding with the Board on this subject, and the greatest interest, and a most gratifying public spirit are said by the members to be met on all sides. The Committee itself has done considerable experimental work,—principally at Buffalo—the material having been, in some cases, gratuitously furnished by manufacturers of rolled beams.

The Committee on Malleable Iron has collated a large mass of valuable information, and the records of a great number of experiments, and, among other important matter, has obtained an extensive collection of experimental determinations of the effect of time upon the elevation of the elastic limit by strain, during periods varying from a few seconds up to a year. The variation of quality due to differences of size and form of section of the bar and the modification of strength, ductility and resilience are under investigation. The Chairman of this Committee is also determining the influence of proportions of test-pieces upon their ultimate resistances.

The Committee on Cast Iron is pursuing a course similar to that of the Committee on Malleable Iron, with similarly promising results.

The Committee on Metallic Alloys has made an investigation of the strength and other properties of bronzes, which may be taken as typical of the kind of work to be done by the Board.

Several series of copper-tin alloys were prepared, varying in some cases by regular percentages, and in others by chemical equivalents, and were cast in bars of 1-inch square section and about 28 inches long. Their temperatures of fusion were taken at casting, and some were cast in sand, and others in an iron ingot mould. The weighing was carefully done in a Coast Survey balance, in the Physical Laboratory of the Stevens Institute of Technology. A set were reserved for the determination of the coefficient of expansion, by Dr. Mayer. The others were broken by transverse stress, one set by dead loads, and others in the transverse testing machine of the Mechanical Laboratory, and deflections and tests were recorded to the fourth place of decimals, in inches, and also in meters with equal precision. The logs were made up, and the results were also laid off graphically. The curves revealed some peculiar and important facts. The fractures were photographed and, where peculiar, were reported upon by Prof. Leeds, the chemist and mineralogist of the Institute. From the data obtained, the coefficients of elasticity were calculated and recorded.

Complete sets were next broken by tension, and the results recorded and worked up as with the transverse tests, and the records and curves compared, and a series of compression specimens were made up as companion test-pieces.

The full series was finally tested in the autographic recording machine and, from the strain-diagrams, their strength, elasticity, ductility, resilience and homogeneousness were deduced, and the law of variation worked up graphically. The effect of strain in elevating the elastic limit was observed.

All specimens were examined by the chemist, and a comparison made between the proportions by mixture and composition in the bar which exhibit the loss of metal, and to some extent, change of physical character, produced by melting and casting. Some curious and interesting scientific facts are revealed by the research, and a new mineral, consisting of stannic acid with a trace of copper, in magnificent needle-shaped crystals was produced in some cases, which has been subjected to examination and analysis by Prof. Leeds.

A determination of specific gravities of the metals as purchased, as cast and as compressed mechanically, and in mass, and in a state of fine division, concludes this research.

A similar research is in progress, under the direction of this Committee, by Prof. Thurston, its Chairman, which is intended, also, to be as complete and accurate an investigation of the copper-zinc alloys as the resources at command will permit.

Before entering upon this work, the Chairman collated all published material bearing on the subject, and a preliminary report of about one hundred pages embodies the most important facts previously determined, and contains the bibliography of this subject of copper-tin alloys. This work was supplemented by making graphical records of the experimental work of Mallet, Mathessen, Calvert, Johnson and others on the conductivity for heat and electricity, and the specific gravity and other properties of copper-tin alloys, as had been examined by them. It was the intention to profit by facts already acquired by acknowledged authorities, to complement them by the new investigations, and to avoid useless repetition of work involving serious expenditure of time.

This paper is itself regarded as exceedingly valuable, and particularly to the mechanical engineer, as it is the first time that these earlier researches have ever been collected and put in an accessible and compact form.

A similar preliminary research is made to preface the examination of the copper-tin-zinc alloys, and the same plan will be pursued throughout.

The Committee on Orthogonal Strains is planning a series of experiments to determine the laws of the resistance of materials under simultaneous stresses acting in rectangular directions, as in the case of a rod subjected to torsional or shearing simultaneously with tensile or compressive stress. The subject has been entirely unstudied up to the present time.

The Committee on Physical Phenomena is preparing to seek for the phenomena induced by stress in the various physical modes of energy, as the development of magnetic, electric and thermal actions. The fact of the development of heat and electricity has long been known, but no systematic or scientific investigation has ever been made in this direction.

The Committee on Steel produced by Modern Processes is working with the Committee on Chemical Research. It is collating also the vast mass of material available and will endeavor to make a report which shall be of great and permanent value.

The Committee on Re-heating and Re-rolling is to test iron, etc., in the several stages of manufacture, refined and unrefined, and to observe the effects of successive re-heats, of re-working and rolling, to determine, if possible, what amount of working is demanded by different irons, and what are the temperatures which will practically give the best results.

The Committee on Steel for Tools is making an extended series of experiments at the Washington Navy Yard to determine the value of various steels for tools. A large collection of steels is made; their composition is determined, and they are there carefully tested by setting them at work—turning, planing, boring and chiselling—and their behavior and their composition being thus ascertained it will probably be easy to learn the chemical and physical characteristics of the best tools. The names of makers are of no importance in this investigation, and are not to be reported. The Board, in all its work, will avoid reference to makers of material in any way that may injure any manufacturer directly or indirectly. Scientific knowledge of directly practical value and engineering facts and figures, solely are sought.

Since that Committee reported, several of these investigations have been completed, and the reports are now completed, or are in preparation.

About 150 steels have been completely analyzed, and the Committee on Chemical Research are making the tests of their physical and mechanical properties for comparison. This work may probably never be completed as the Committee have not sufficient funds.

The Committees on Wrought Iron, or Re-heating and Re-rolling and on Cables, make a common report which is completed. In this report, the information above outlined is carefully collated, and it is expected that the facts and data given will be valuable to all makers and users of iron, and especially those portions which analyze and describe the effects of the several details of processes of making and rolling iron, the effects of various kinds of strain, and the results of the attempts made to determine the best method of making cables for large vessels, and to determine how uniform strength can be secured in iron of different sizes in the bar, and how to make large masses equally strong with small pieces.

The report of the Committee on Metallic Alloys,—containing 600 pages of manuscript with illustrations, tables of date and diagrams — is completed so far as it relates to the copper-tin alloys. The work on the other alloys, copper-zinc and copper-tin-zinc, is done, and those reports are in preparation. The result of all this work is comprised within the smallest possible compass, in the small model here exhibited[1] on which the strength of all possible alloys of these three classes is shown by ordinates measuring 25,000 pounds per square inch, for each vertical inch of the ordinate. On this little triangular plate, every possible composition of the three metals, copper, zinc and tin — whether combined two or three together — is represented. Similar models may be made to represent the ductility of all these alloys, or the resilience, or the elasticity, or any other quality which has been determined. It will be observed that we have here a beautifully accurate method of ascertaining maxima. It will be seen when the model is studied that a maximum occurs when a composition containing nearly the proportions of Muntz metal with about two or three per cent. of tin is found, and it will be seen that a very slight deviation in either direction from this exact mixture, reduces the strength immensely. In one direction a change of but a few per cent. makes a metal so brittle that it falls to pieces in the mould. It is also seen that the strength of certain alloys can be calculated from their composition, a very simple formula giving the range of compositions of maximum strength: —

Thus, $Z + 4\ Sn = M$ may be taken as one, in which Z is the percentage of zinc, Sn that of tin in any triple alloys, and M the total which give a composition of maximum strength. That strength is not far from

---

[1] See illustration accompanying paper "On a New Method of Planning Researches," etc.

$$40{,}000 + \tfrac{1}{2}\,Z = \text{Tenacity}$$

where Z is the percentage of zinc, in those alloys of maximum strength. Again, for copper-tin alloys of from 0 to 20 per cent. tin, the tenacity is not far from

$$30{,}000 + 1{,}000\,Sn = T$$

where Sn is the percentage of tin present, the alloys having been well fluxed and the casting perfectly sound. For brass, the formula would be approximately within certain limits,

$$30{,}000 + \tfrac{1}{2}\,Z = T.$$

The other Committees than those named have not reported, but it is hoped that, if properly supported by Congress, they will all have valuable information to give.

There seems to have been no opposition to the continuance of this Commission inside or outside the halls of Congress, except in the House Committee on Appropriations, where some members have not become convinced that the work of the Board is as important in its way as that of the several Bureaus of the Department of the Interior, including the Patent Office; that it is the only way in which the mineral resources of the country and the metal industries can be effectively developed, and that in no other way can the engineers who design, and the manufacturers who build all works in which metal is used, obtain that exact knowledge of their materials which is essential to the security of their constructions.

It is, to a certain degree, a satisfaction to be able to report that, although our own legislators have shown so little appreciation of the importance of a national work like this, those of other countries have been quick to take the hint given them, and that inquiries have come from several directions respecting the organization, and the methods of work of the Board which indicate that similar commissions will probably be organized in other countries, and that, so far as the scientific results aimed at are concerned, we may hope to see good work done, although we must forego the credit of having ourselves done that work, and notwithstanding the fact that the commercial benefit hoped for is the direct consequence of the work of our own Board.

It is greatly to be regretted that the business and scientific men of the country have permitted their influence to become of so little weight at the national capital. The work of this Board has been demanded by nearly all of the principal organizations of business men, by the scientific schools and by the faculties of many of the colleges of the country, and memorials have been presented in Congress, asking liberal support for the Board, from the American Iron and Steel Association, the American Society of Civil Engineers, the American Institute of Mining Engineers, the several institutes of technology, and from other institutions; but our representatives have taken far less interest in the matter than should have been expected, and the House Committee on Appropriations have actually introduced into their last appropriation bill a provision for the discharge of the Board at the end of the present fiscal year.

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CLVI.

(Vol. VII. March, 1878.)

ON A NEW METHOD OF DETECTING OVERSTRAIN IN IRON AND OTHER METALS, AND ON ITS APPLICATION IN THE INVESTIGATION OF THE CAUSES OF ACCIDENTS TO BRIDGES AND OTHER CONSTRUCTIONS.

A Paper by ROBERT H. THURSTON, C. E., Member of the Society.

READ MARCH 20TH, 1878.

It has been shown by the writer* and by other investigators that, when a metal is subjected to stress exceeding that required to strain it beyond its original apparent, or "primitive," elastic limit, this primitive elastic limit becomes elevated, and that strain-diagrams obtained autographically, or by carefully plotting the results of well conducted tests of such metal, are "the *loçi* of the successive limits of elasticity of the metal at the successive positions of set."†

It has been shown by the writer also that, at the successive positions of set, strain being intermitted, a new elastic limit is, on renewing the application of the distorting force, found to exist at a point which approximately measures the magnitude of the load at the moment of intermission.*

---

* See Trans. Am. Soc. C. E., 1874, *et seq.*, Journal Franklin Institute, 1874; Van Nostrand's Eclectic Engineering Magazine, 1874, etc., etc.

† On the strength, etc., of Materials of Construction. 1874, Sec. 20.

It has been still further shown by the writer, and by Commander Beardslee, U. S. N., by direct experiment in the Mechanical Laboratory of the Stevens Institute of Technology, and at the Washington Navy Yard, that the normal elastic limit, as exhibited on strain-diagrams of tests conducted without intermission of stress, is exalted or depressed when intermission of distortion occurs, according as the metal belongs to the iron or to the tin class.† This elevation of the normal elastic limit by intermitting strain is, as has been shown, variable in amount with different materials of the iron class and the rate at which this exaltation progresses is also variable. With the same material and under the same conditions of manufacture and of subsequent treatment, the rate of exaltation is quite definite and may be expressed by a very simple formula. The writer has experimented with bridge material, and Commander Beardslee has examined metal specially adapted for use in chain cables, for which latter purpose an iron is required, as in bridge building, to be tough as well as strong and uniform in structure and composition. The experiments of the latter investigator have extended to a wider range than have those of the writer, and the effect of the intermission of strains considerably exceeding the primitive elastic limit has been determined by him for periods of from one minute to one year.‡ From a study of the results of such researches and from a comparison with the latter investigation, which was found to be confirmatory of the deduction, the writer has found that, with such iron as is here described, the process of exaltation of the normal elastic limit due to any given degree of strain usually nearly reaches a maximum in the course of a few days of rest after strain, its progress being rapid at first and the rate of increase quickly diminishing with time. For good bridge irons, the amount of the excess of the exalted limit, as shown by subsequent test, above the stress at which the load had been previously removed may be expressed approximately by the formula :

$$E^1 = 5 \text{ Log. } T + 1.50 \text{ per cent.};$$

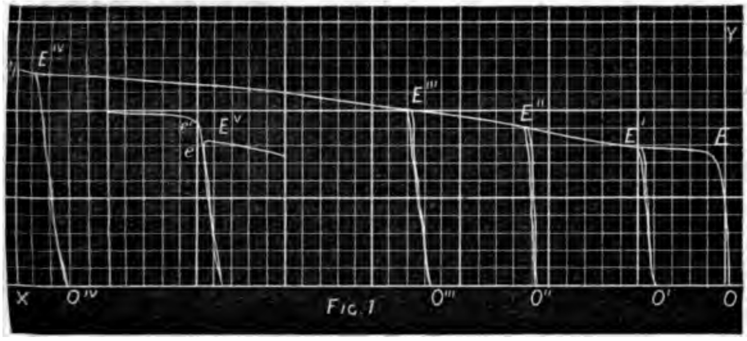
in which the time, T, is given in hours of rest after removal of the tensile stress which produced the noted stretch.

---

* On the Mechanical Treatment of Metals ; Metallurgical Review, 1877 ; Engineering and Mining Journal, 1877.

† Trans. Am. Soc. C. E., 1877.

‡ The result on this investigation is completed and will be presented to the President of the United States by the United States Board appointed to test iron, steel, etc.



Thus, in the figure, which is a facsimile of a part of a strain-diagram produced by such an iron, during a test in which the intermission of stress was of too brief duration to cause an observable exaltation of the normal elastic limit in a diagram drawn on so small a scale, the point E is the primitive elastic limit of the material, and E^{I} E^{II} E^{III} E^{IV}, are the normal elastic limits corresponding to sets under loads which have strained it beyond that primitive elastic limit. In the example here illustrated, the primitive limit is found at about 20,000 pounds per square inch, or 1,400 kilograms per square centimeter, and the other points are those corresponding to loads of, respectively, 21,000, 22,500, 25,000 and 30,000 pounds on the inch, or to 1 470, 1 575, 1 750 and 2 100 kilograms on the square centimeter. The corresponding extensions, as shown on the diagram, are 1.25, 2.53, 4.50 and 6.78 per cent.

Had the stress been intermitted at either of these points any considerable period of time, there would have been observed a rise in the diagram as above stated like that shown in Fig. 1, at E^{V} the normal elastic limit *e*, being, on subsequent test, found altered and a new limit, *e'*, observed. The extent of this elevation of the limit would be the greater as the time of rest was greater, as already seen.

Thus, it is seen that a metal, once overstrained, carries, permanently, unmistakable evidence of the fact* and can be made to reveal the amount of such overstrain at any later time with a fair degree of accuracy. This evidence cannot be entirely destroyed, even by a moderate degree of annealing. Often, only annealing from a high heat, or reheating and reworking, can remove it absolutely. Thus, too, a structure, broken down by causes producing overstrain in its tension members, or in its transversely loaded beams (and, probably, in compression members—although the writer is not yet fully assured of the latter), retains in every piece a register of the maximum load to which that piece has ever been subjected; and the strain-sheet of the structure, as strained at the instant of breaking down, can be thus laid down with a fair degree of certainty.

---

* The writer has found by subsequent tests, that transverse strain produces the same effect upon the elastic limit for tension.

Here, then, when the work above detailed shall have been properly complemented with experimental determinations of the behavior of all the materials of general use in construction, may be found a means of tracing the overstrains which have resulted in the destruction or the injury of any iron or steel structure, and of ascertaining the cause and the method of its failure, in cases frequently happening in which they are indeterminable by any of the usual methods of investigation.

The fact of the normal variation of the elastic limit, as change of form progresses under gradually increased load, has been well established by the experiments of Hodgkinson, Clark, Mallett, and other English investigators; by Tresca, particularly, in France; by Werder and Bauschinger in Germany, and by Beardslee, the writer and others in the United States.

The exaltation of the series of normal limits so produced, still further, as shown by the writer and as seen in Fig. 1, by the intermission of strain, as at E^{v}, is also a matter of no uncertainty as to its character, although much more study is needed to determine the modifying effects of time of intermission on metals of the two great classes and of differing composition. The method above outlined of determining the extent of previous overstrain may therefore be expected to have many useful applications.

In illustration of an application of the facts thus reviewed to the determination of the causes and the method of the injury or the destruction of a structure, assume the existence of a set of conditions which is familiar to, probably, every engineer in the country who has seen much of the Howe truss, and of some other forms of bridges, as frequently built before the present generation of professional bridge builders effected a revolution in that department of engineering construction.

Suppose one of these bridges to have been built with a span of 150 feet and to have been given such proportions that, with a weight of 1,200 pounds per running foot and a load of one ton per running foot, the maximum stress on end-rods, or other members most strained, is as high as 20 000 pounds per square inch of section of metal. Suppose this bridge to have its tension members composed of a fair, but unrefined, iron, having an elastic limit at about 17 000 pounds per inch, and a tenacity of 45 000 to 48 000 pounds, and with an extensibility of about 20 per cent.

Suppose this structure to break down under a load exceeding that usually sustained in ordinary work, and the cause of the disaster to be "involved in mystery."

Suppose portions of the several tension members to be subsequently removed, and, a few days after the accident, to be carefully tested, with the following results :

	Elastic Limit.	Tenacity.
Sample No. 1	16 500	46 000
" " 2	18 000	48 000
" " 3	30 000	48 000
" " 4	22 500	50 000
" " 5	25 000	52 000
" " 6	27 500	52 000
" " 7	28 000	52 000
" " 8	30 000	52 000
" " 9	32 000	53 000
" " 10	34 000	53 000

And that the extensibility is found to be as little as from ten to fifteen per cent.

Suppose it to be found that the tension members were straight bolts without upset ends, the threads being cut, as was once common, in such a manner that the section at the bottom of the thread is one-third less than the sectional area of the body of the bar. Suppose, finally, that the location of the tested pieces in the structure being noted, it is found that the stronger metal, having also the highest elastic limit, came from the neighborhood of the point at which the bridge gave way, and that the weakest metal and that exhibiting the lowest elastic limit came usually from points more or less remote from the break. It is not likely that in all cases the increase in the altitude of the elastic limit and the increase noted in the ultimate strength of the samples would exhibit a regular order coincident with the order of the rods as to position in the structure ; since the magnitude and the arrangement of the bars would, to a certain extent, determine the relative amounts of strain thrown upon them by overloading any one part of the truss. For present purposes we may assume the order of arrangement to be thus coincident.

On examination of the figures as above given, the engineer would conclude : First, that the original apparent elastic limit of the iron used in this case must have been not far from 17 000 pounds per square inch and that its tenacity was between 46 000 and 48 000 pounds; secondly, that this primitive elastic limit had been elevated, by subsequent loads exceeding that amount, to the higher figures given by the bars numbered from 3 to 10 inclusive; thirdly, that the ultimate strength of the material had been, in some examples given above, increased by similarly intermitted strain.

It would be concluded that the ordinary loads, such as had been carried previously to the entrance upon the bridge of that which caused its destruction, never exceeded, in their straining action, 16 500 pounds per square inch of section of tension rod at the part of the truss from which No. 1 had been taken, and that the other rods tested had carried, probably, at the time of the accident, loads approximately equal to those required to strain them to the extent measured by their elastic limits at the time of testing them.

It would be concluded that the rod from which No. 10 was cut was either that most strained by the load, and therefore nearest the point of fracture of the truss, or that it was very near that point, and it would be made the basis of comparison in further studying the case.

As this elastic limit approaches most nearly the breaking strength of the metal, we may apply the formula for the elevation of the elastic limit with time after intermitted strain which has been above given as derived from tests of a metal of very similar quality. Taking the time of intermission as one week, the extent of the increase has a probable value not far from $E' = 5 \log. 168 + 1.5 =$ nearly 12½ per cent. The magnitude of the stress upon this piece at the time of the accident was therefore 34 000 less one-ninth of that value, or about 30 000 pounds per square inch of cross-section of the bar. This corresponds to about 45 000 pounds per square inch at the bottom of the thread, and is within five per cent. of the primitive breaking strength of the iron. The bar, if broken at the screwed portion, has therefore yielded either under a dead load which was at least equal to its maximum resistance, or under a smaller load acting so suddenly as to have the effect of a real "live load." Or the slight difference here noted may be due to a flaw at the point of fracture. However that may be, it is almost certain that the body of the rod has sustained a stress of not far from 30 000 pounds per square inch.

But it is found, on further investigation, that the load on the structure at the time of the accident was but sufficient to make the maximum stress on these rods—if properly distributed—20 000 pounds per square inch at the threaded part of the piece; which piece, it has been seen, has been broken by a strain nearly double that figure. The fact is at once inferable that the load came upon these members with such suddenness as to have at least the effect of a live load (as taken in the text-books) and giving a maximum stress equal to twice that produced by the same load gradually applied, *i. e.*, the case in which the load falls, through a height equal to the extension of the piece strained by it, the resistances being assumed to increase directly as the extension up to the point of rupture, —an assumption which is approximately correct for brittle materials like hard cast iron, but quite erroneous in the case of some ductile materials, which latter sometimes give a "work of ultimate resistance" amounting to three-fourths or even five-sixths of the product of maximum resistance by the extension.

This accident was therefore caused by the entrance upon the bridge of a load capable of straining the metal to about one-half of its ultimate strength, if slowly applied, but which, in consequence of its sudden application, doubled that stress.

This sudden action may have been a consequence either of its coming upon the structure at a very high speed, or a result of the loosening of a nut, or of the breaking of a part of either the bridge floor or of one of the tracks of the train. The latter occurrence, permitting the load to fall even a very small distance, would be sufficient.

This paper is not presented as a perfectly satisfactory statement of definite facts from which absolutely reliable conclusions can be drawn. The whole subject is deserving, however, of very careful and very extended experimental investigation, and the writer has been able to obtain but a small amount of satisfactory definite information in regard to it as yet. The figures given do not exactly represent those obtained from any actual case. They do, however, fairly illustrate the limited experience of the writer, and are nearly exact for at least one case; they may serve to indicate the possible value of the cautious application of the method here outlined of studying the causes of such accidents as are considered in the hypothetical case here taken.

The same method may sometimes be used to ascertain the probable cause of a boiler explosion by determining whether the metal has been subjected to overstrain in consequence of overpressure. The causes of accidents to machinery may also be thus detected, and many other applications will suggest themselves to every engineer.

945-9

A NEW TREATISE

ON

ELEMENTS OF MECHANICS

ESTABLISHING STRICT PRECISION

IN THE MEANING OF

DYNAMICAL TERMS

ACCOMPANIED WITH AN

APPENDIX

ON

DUODENAL ARITHMETIC AND METROLOGY.

BY

JOHN W. NYSTROM, C. E.

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PUBLISHED FOR THE AUTHOR.

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TO

WILLIAM SELLERS, ESQ.,

THIS WORK IS RESPECTFULLY DEDICATED,

AS A MARK OF APPRECIATION OF HIS

DISTINGUISHED ACCOMPLISHMENTS

IN THE MECHANIC ARTS,

BY THE AUTHOR.

PREFACE.

THE principal objects in introducing this new treatise on mechanics are the establishment of strict precision in the meaning of dynamical terms, and the classification of physical quantities into elements and functions.

A revision of the principles of mechanics is a necessity long felt, and frequently acknowledged in the discussions of learned men, who have heretofore disagreed as to the true meaning of technical terms and the constitution of dynamical quantities.

The prevalent discordance on these topics has caused the delay of this publication for over ten years, in which interim various discussions thereupon have been published, both in Europe and in America, indicating the confused condition of the subject.

In scientific periodicals we rarely find a sound article on dynamics, but the action and combination of physical elements are treated as if governed by individual judgment, instead of the fixed and immutable ordinances of nature.

A pamphlet entitled *Principles of Dynamics*, exposing the confusion in the science of dynamics, has been published and presented to the principal libraries and institutions of learning.

In addition to the objects above mentioned, this treatise contains sufficient new and original matter to warrant its publication.

The Appendix is added for the purpose of supplying the student with materials for the coming revision and final establishment of an international system of metrology, which must be attended to sooner or later.

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INTRODUCTION.

THIS treatise is written for students of Mechanics, and the technical terms herein adopted are those used in the machine-shop, rejecting the ideal vocabulary heretofore used in text-books and colleges.

In order to establish a standard language in Mechanics, it is hoped that institutions of learning will approve and confirm the terms and distinctions of dynamical quantities as adopted and defined in these pages, 57 to 69, inclusive.

The distinction between the terms *force*, *power* and *work* has heretofore not been clearly defined, but either of these terms has been promiscuously applied to either or all those quantities, according to individual caprices.

Work has thus been distinguished by a variety of terms indicating different characters of that function. It has generally been maintained that work is independent of time, and that power is dependent on time, both of which propositions are incorrect.

REJECTED TERMS.

Energy. This term is used to denote work, but the sense of it conveys an idea of a different virtue—namely, that of activity or vigor, which is power. We say that a man has a great deal of energy when he can accomplish much work in a short time, which is a virtue of power; but if he accomplishes the same quantity of work in a much longer time, we do not give him credit for much energy. The term energy, if employed at all, ought to be applied to power alone; but as we have the expressive term *power* for that function, it is better to dispense with the term energy in dynamics.

The term *work* is the proper name for the function which has been called energy.

Quantity of Motion is a term also used to denote work, which latter is a different function from that of motion. The sense of this term is inseparably associated with an idea of more or less space, which is a function of velocity and time without regard to force; and as force is an element of work, the term *quantity of motion* should be rejected as improper to denote that function.

The words **Actual, Total, Quantity, Mode, Potential, Intrinsic, Kinetic Effort,** etc. are often appended to terms without affecting the *nature* of the quantity so denoted; the objection to which is that one and the same quantity is differently defined according to the combination of these appended words.

As an illustration of the effect of these appendages to terms in dynamics, we may apply them to geometrical quantities; for instance, *volume* in geometry corresponds to *work* in dynamics, and may be expressed thus:

Volume of a cube.
Cubical volume of a sphere.
Total intrinsic volume of a cone.
Actual potential volume of a cylinder.
Total intrinsic quantity of volume of a pyramid.
The actual total quantity of voluminous cubic inches in an intrinsic cubic foot is 1728. (A cubic foot is 1728 cubic inches.)

All these expressions mean simply *volume;* as the different combinations of terms denoting work mean simply work, or the product of the three simple elements **force, velocity** and **time.**

The rejection of the superfluous terms will render the subject of dynamics much easier to teach, learn and remember.

There is also an expression generally used in the English language —namely, "*Consumption of coal per horse-power per hour,*" which is not correct, or rather it is nonsense. The intended idea should be expressed, "*Consumption of coal per hour per horse-power.*" It is the fuel which is divided by time, and not the power.

The consumption of fuel is work, which divided by time is power.

There exists no such quantity in dynamics as power per time, but power multiplied by time is work, and work per time is power.

The following list shows which terms are herein rejected and adopted:

DYNAMICAL TERMS.

Rejected Terms.	**Reason for Rejection.**
Effort of force.	Means simply force.
Efficiency of force.	" " "
Acting force.	All forces act.
Force of motion.	Means motive force.
Working force.	" " "
Quantity of moving force.	" " "
Quantity of motion.	Has no definite meaning.
Mode of motion.	" " "
Mode of force.	" " "
Moment of activity.	Means simply power.
Mechanical power.	" " "
Mechanical effect.	" " "
Quantity of action.	" " "
Efficiency.	" " "
Rate of work.	" " "
Dynamic effect.	Used for power or work.
Quantity of work.	Means simply work.
Actual total quantity of work.	" " "
Total amount of work.	" " "
Actuated work.	" " "
Vis-viva.	" " "
Living force.	" " "
Energy.	" " "
Actual energy.	" " "
Potential energy.	" " "
Kinetic energy.	" " "
Energy of motion.	" " "
Energy of force.	" " "
Heat a form of energy.	" " "
Heat a mode of motion.	" " "
Mechanical potential energy.	" " "
Quantity of energy.	" " "
Stored energy.	" " "
Intrinsic energy.	" " "
Total actual energy.	" " "
Work of energy.	" " "
Equation of energy.	Formula for work.
Equality of energy.	Primitive and realized work.

DYNAMICS COMPARED WITH GEOMETRY.

§ 2. In geometry we have three fundamental elements, expressed by the terms **Length, Breadth** and **Thickness,** which serve to represent to the mind the nature of the several properties of geometrical space.

We have in like manner in dynamics three fundamental elements, expressed by the terms **Force, Velocity** and **Time,** which represent the nature of physical **Power, Space** and **Work.**

Force is any action which can be expressed simply by weight without regard to motion or time; it is an essential principle which cannot be resolved into two or more principles, and is therefore a simple element. *Force* is the first element in dynamics, and corresponds to length in geometry.

Velocity is speed or rate of motion, an essential principle which cannot be resolved into two or more principles, and is therefore a simple element. *Velocity* is the second element in dynamics, and corresponds to breadth in geometry.

Time is duration, or that measured by a clock; it is an essential principle which cannot be resolved into two or more principles, and is therefore a simple element. *Time* is the third element in dynamics, and corresponds to thickness in geometry.

Power is the product of the first and second elements, *force* and *velocity*, and is therefore a function.

Power is the first function in dynamics, and corresponds to the product of length and breadth, which is surface in geometry.

Space is the product of the second and third elements, *velocity* and *time*, and is therefore a function.

Space is the second function in dynamics, and corresponds to the product of breadth and thickness, which is the area of a cross-section of a solid in geometry.

Work is the product of the three simple elements *force*, *velocity* and *time*, and is therefore a function.

Work is the third function in dynamics, and corresponds to the product of length, breadth and thickness,which is volume in geometry.

Work is also the product of the element *force* and function *space*, because the function space contains the elements *velocity* and *time*: like volume in geometry, it is the product of length and area of cross-section.

Work is also the product of the function *power* and element *time*, because the function power contains the elements *force* and *velocity*: like volume in geometry, it is the product of area and thickness.

DYNAMICS.

§ 1. **Dynamics** is that branch of mechanics which treats of *forces in motion*, producing *power* and *work*. It comprehends the action of all kinds of machinery, manual and animal labor in the transformation of physical work.

Quantity is any principle or magnitude which can be increased or diminished by augmentation or abatement of homogeneous parts, and which can be expressed by a number.

Element is an essential principle which cannot be resolved into two or more different principles.

Function is any compound result or product of two or more different elements.

A function is resolved by dividing it with one or more of its elements.

Force, Velocity and **Time** are simple physical elements.

Power, Space and **Work** are functions of those elements.

The combinations of the elements in the functions are as follows:

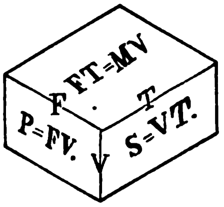
ELEMENTS.	FUNCTIONS.
Force $= F.$	Power $P = F\ V.$
Velocity $= V.$	Space $S = V\ T.$
Time $= T.$	Work $K = F\ V\ T.$
Mass $= M.$	Work $K = \frac{1}{2} M\ V^2.$

Fig. 59.

$F : M = V : T.$

MOMENTUM.

$M\ V = F\ T.$



$F : M = \frac{1}{2} V^2 : S.$

WORK.

$F S = \frac{1}{2} M\ V^2.$

These are the fundamental principles in dynamics.

SUMMARY OF INHABITATION AND CIVILIZATION IN WORLDS.

Inhabitants of other worlds are as comfortable with their combination of material and physical elements as we are with ours. They have different lengths of years, seasons, nights and days; different force of attraction, atmospheric pressure, light and heat, as shown in the table of elements of our planetary system. A body weighing one pound on the earth's surface weighs 2.456 pounds on *Jupiter*, and only half a pound on the planet *Mars*. The light on the surface of *Uranus* is only 0.003 of that on the Earth, but the optical organs of its inhabitants (if such exist) are constructed accordingly, so as to render them as comfortable with their light as we with ours.

Each variety of inhabitants is necessarily accommodated to the conditions of the operating elements, the most perfect organizations requiring more complicated elementary combinations.

We can justly claim that man is the most perfect organization known on our earth, but that claim cannot be extended to other worlds, particularly as long as we maintain armies and navies for offensive and defensive purposes; whilst the various forms of mischief, egoism and malignity which exist among men on earth, do not speak well for their civilization.

Considering the progress of man within the scope of history, and the fact that a large portion of the human race is yet in its primitive state, totally estranged from the surrounding progress, it appears that our earth cannot be very old in its present permanent condition. The idea of age in this connection comprehends millions of years.

We have good reason for supposing that organizations in other worlds outside of our system are far superior to our own, because the character of organizations does not depend only upon the existence of all the material and physical elements, but principally upon their proportions and distribution, which are evidently better classified in other worlds or in permanent nebulas existing millions of years before our earth was formed. The superior organizations in such old worlds have advantages not only in time and experience, but in greater varieties of physical phenomena upon which to exercise their knowledge and intelligence.

They may be sufficiently advanced in the science of optics to be able to extend their vision to our earth and examine our doings.

We can therefore be convinced that there exist in other worlds beings which are far superior to ourselves, whilst above all presides *the Creator of the Universe*, who superintends these myriad organizations, whose infinite inventions testify to His exhaustless and eternal power.

§ 194. DYNAMICS OF SOUND.

Sound is work, consisting of the three simple elements $F\ V\ T$, of which F = force of the sound, V = velocity of vibration, and T = time of continuance of the sound.

The loudness of sound is

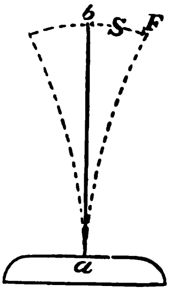
$$\text{Power} \qquad P = F\,V.$$

The pitch of the sound indicates the proportion between F and V.

Two different sounds of different pitch may be of equal power or loudness, but the high-pitch sound is then produced by small force F and great velocity V, whilst the low-pitch sound is produced by greater force F' and smaller velocity V', so that the products $F\ V$ and $F'\ V'$ are alike in the two sounds.

Let an elastic spring $a\ b$ be drawn aside a space S where the force is F. Leave the spring to take its own course, and it will move fore and back and set the surrounding air into vibration, which produces sound.

Fig. 224.



The work expended in drawing the spring aside is $K = F\,S$, which work is restored by producing sound, and the spring will continue to sound until all the work $F\,S$ is consumed.

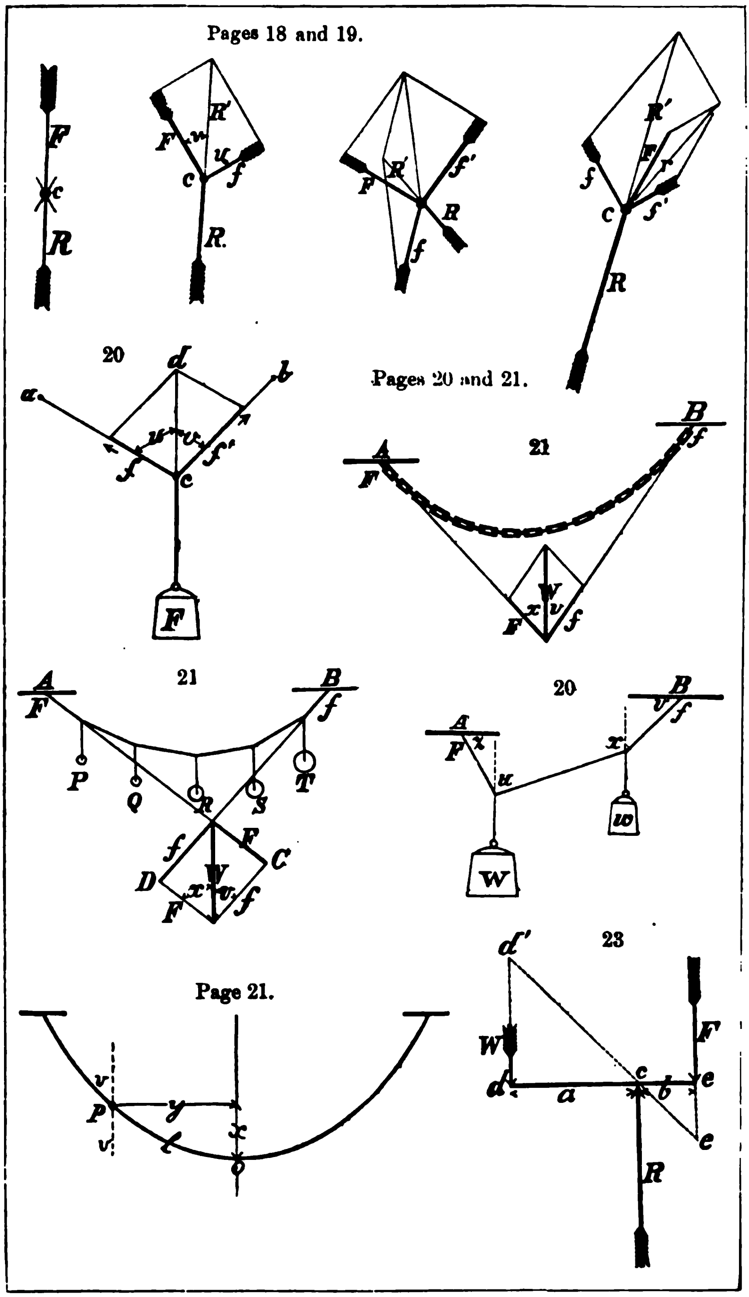
The loudness or power $P = F\,V$ of the sound is greatest at the start of vibration, after which it will gradually diminish, and finally fade away to nothing.

Differential work $\delta k = P\delta t$, but the power decreases as the time increases that we can place $P = \frac{C}{t}$, in which C is a constant factor.

$$\delta k = \frac{C\delta t}{t}, \qquad K = \int \frac{C\delta t}{t} = C\ hyp.log.T.$$

$$\text{Time of sound, } hyp.log.T = \frac{K}{C} = \frac{F\,S}{C}.$$

The force F of an elastic spring is as the space S within the limit of vibration, and the mean force in the space S is therefore $\frac{1}{2}F$. The spring vibrates the same pitch of sound in any space S, and the proportion between F and V is therefore constant. The loudness of the sound or power $P = F\ V = C\,S^2$, or the power of the sound, is as the square of the space of vibration. The velocity V in the above formulas means that of the force producing the sound, and not the velocity of the sound from the sonorous body.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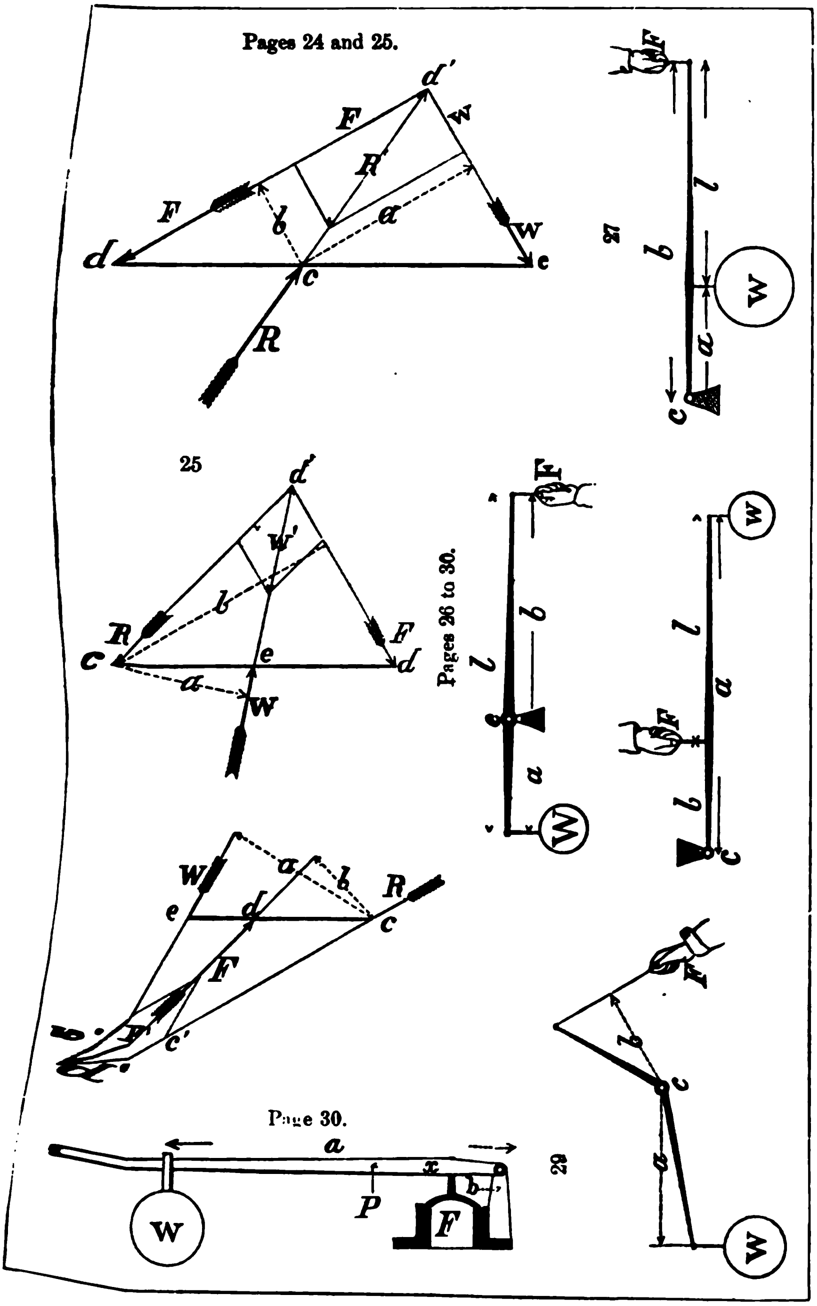
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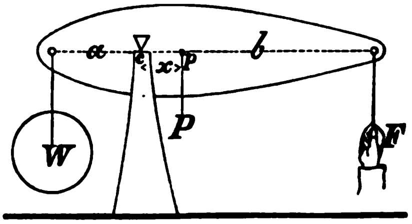

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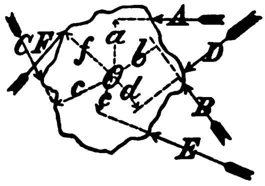

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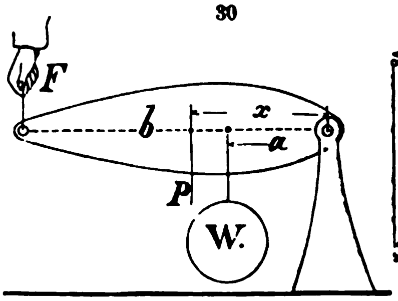

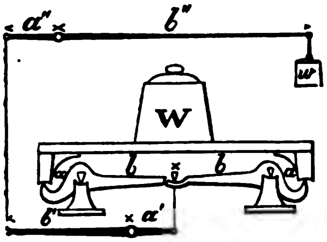

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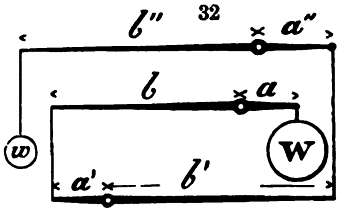

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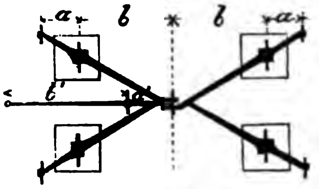

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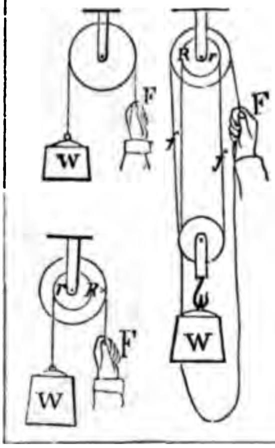

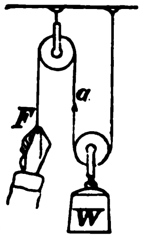

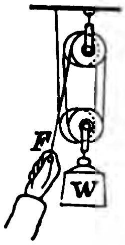

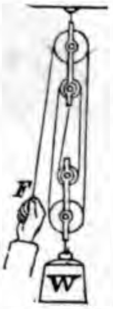

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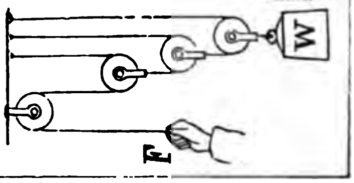

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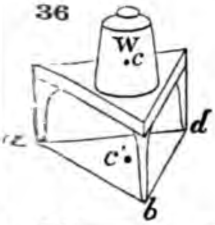

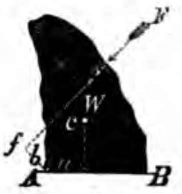

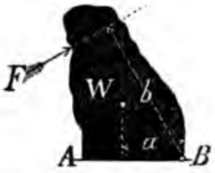

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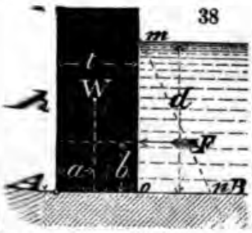

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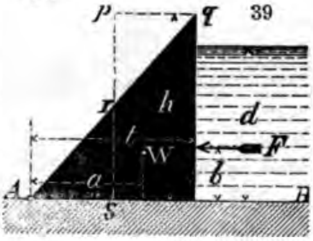

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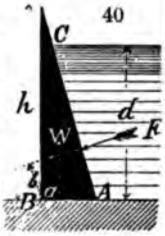

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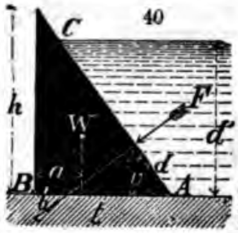

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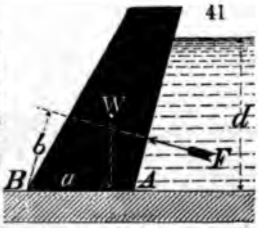

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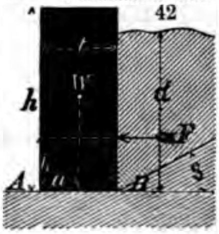

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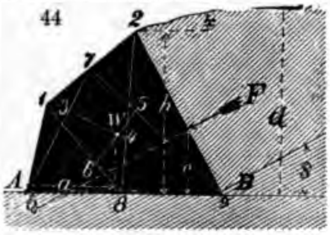

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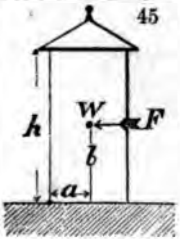

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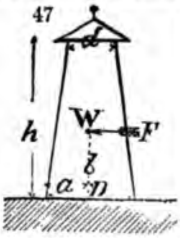

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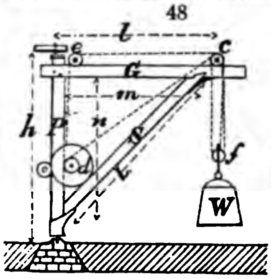

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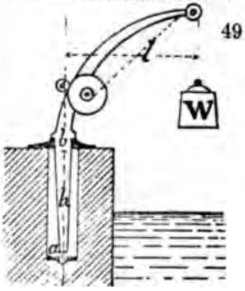

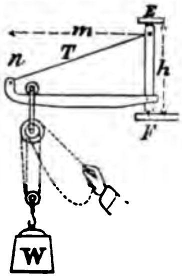

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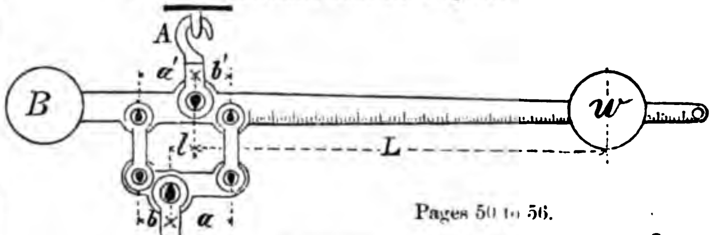

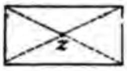

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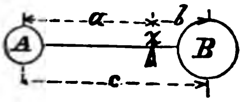

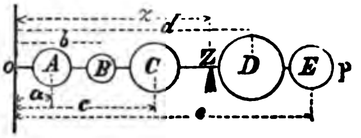

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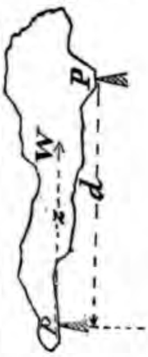

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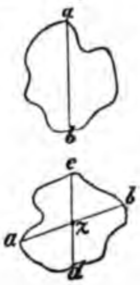

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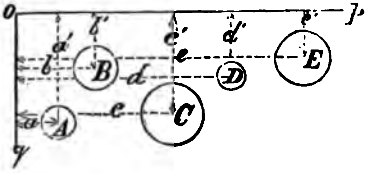

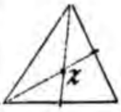

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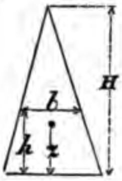

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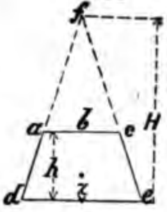

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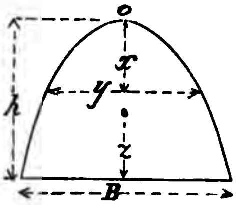

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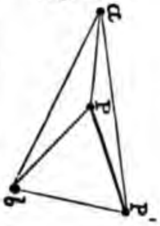

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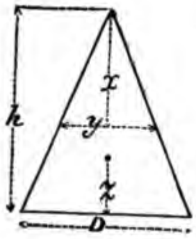

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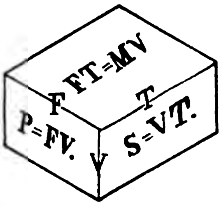

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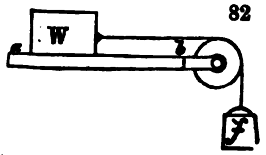

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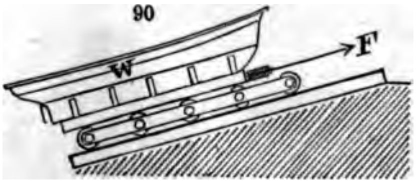

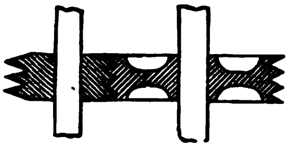

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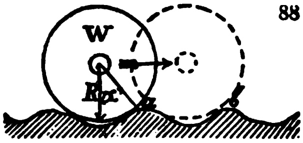

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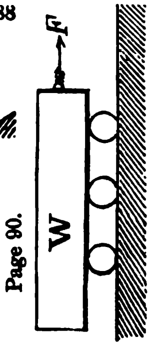

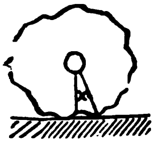

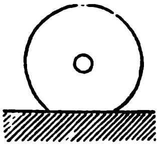

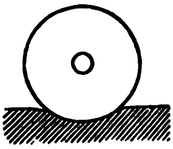

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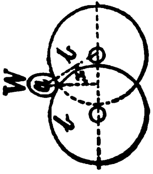

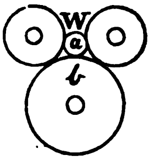

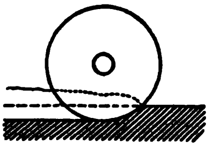

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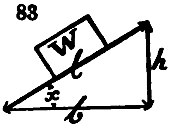

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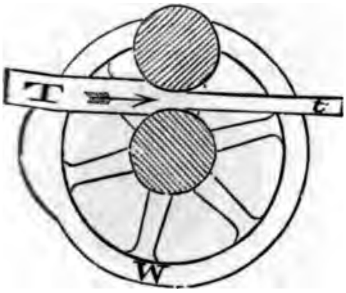

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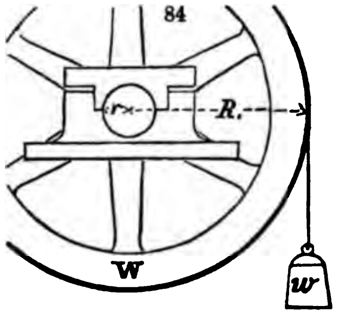

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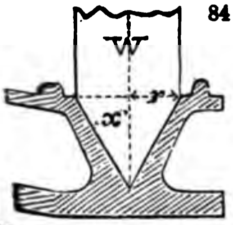

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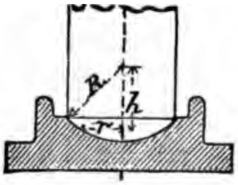

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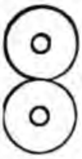

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IMPROVED "DIPPER-DREDGE."

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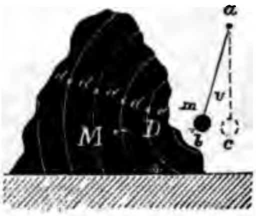

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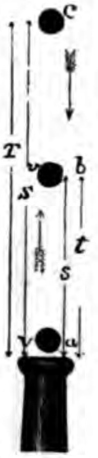

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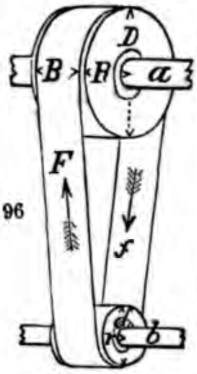

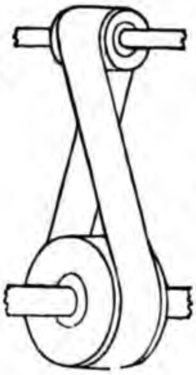

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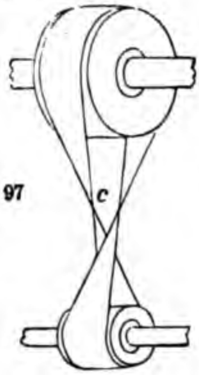

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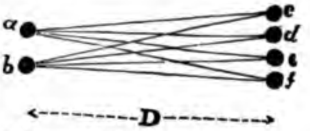

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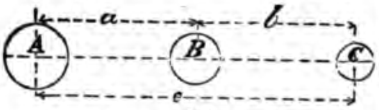

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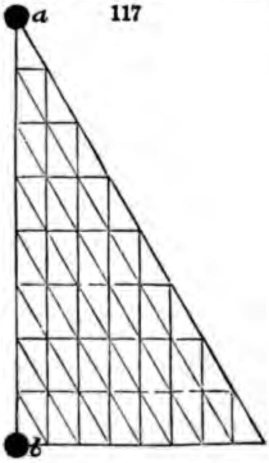

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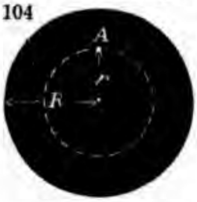

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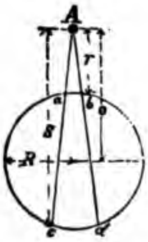

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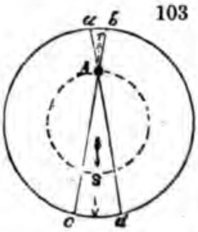

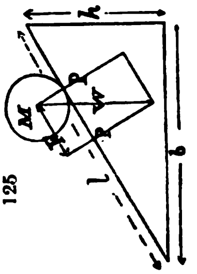

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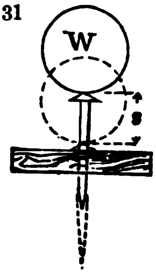

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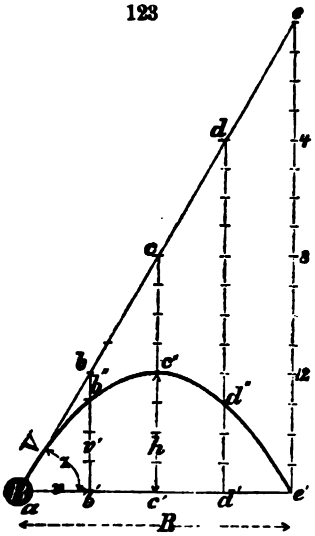

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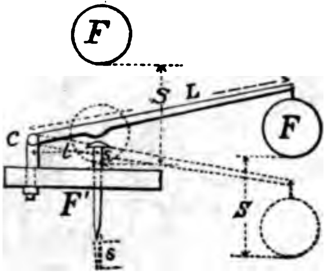

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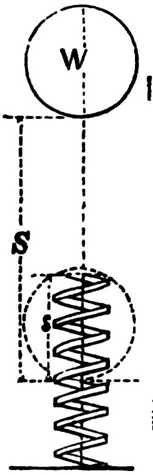

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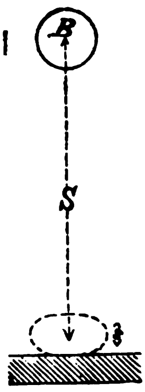

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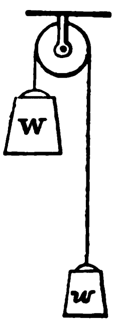

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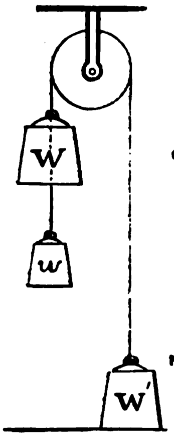

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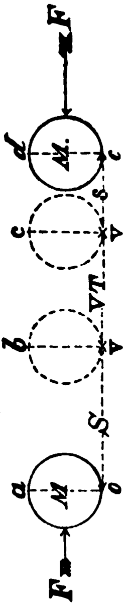

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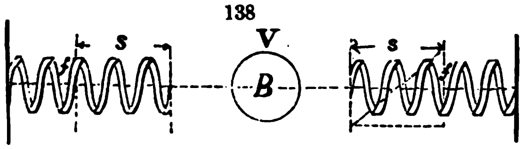

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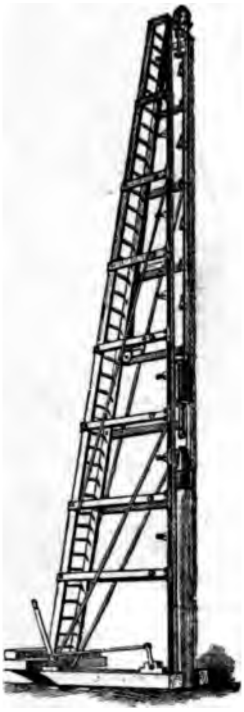

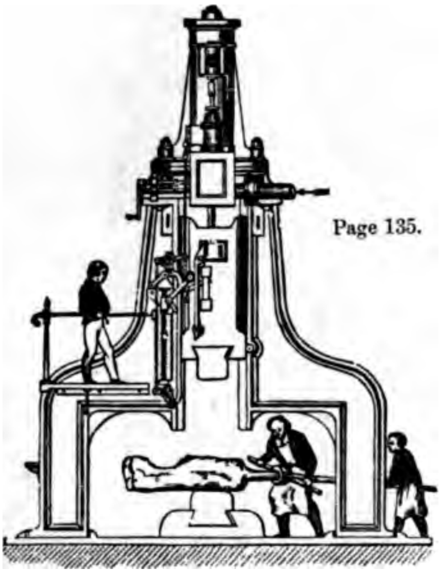

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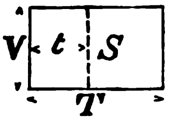

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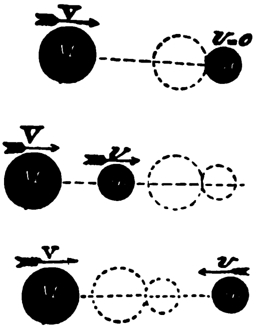

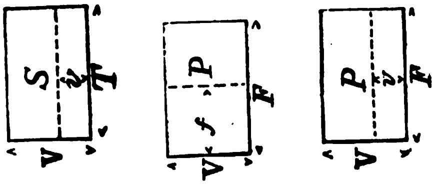

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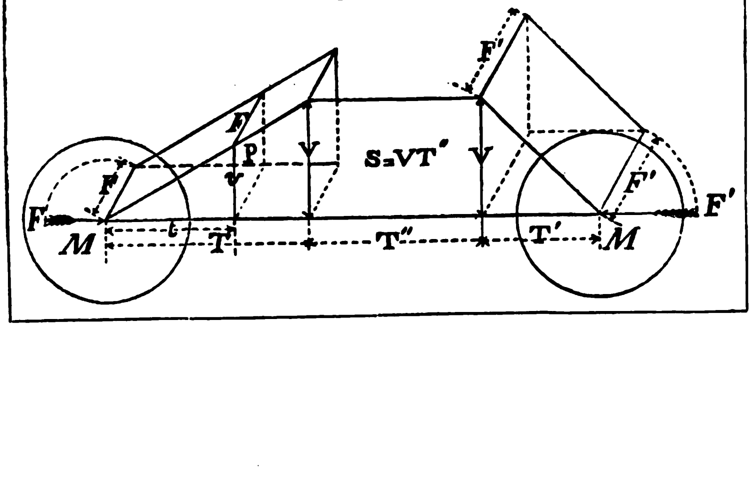

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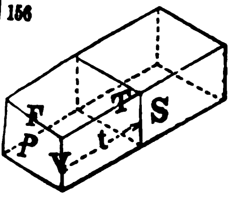

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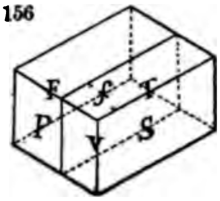

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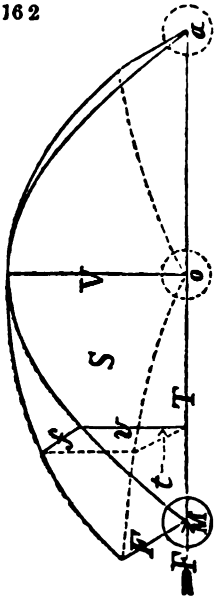

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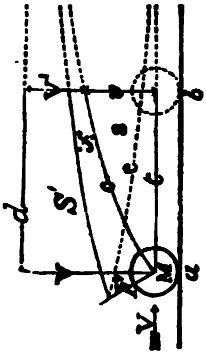

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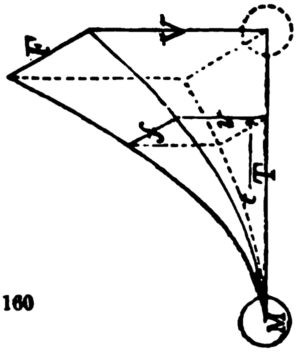

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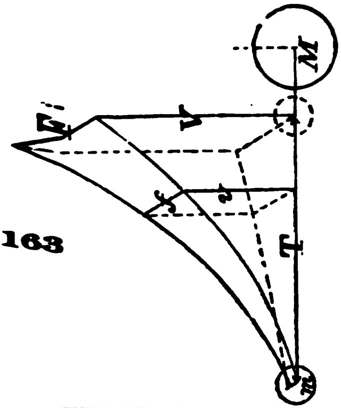

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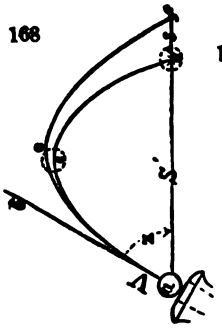

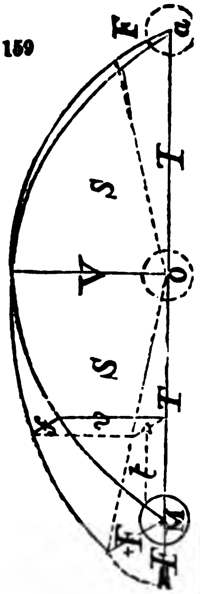

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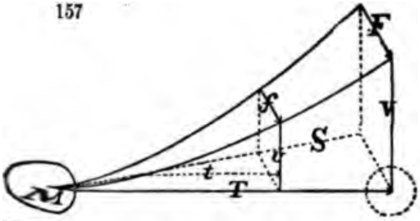

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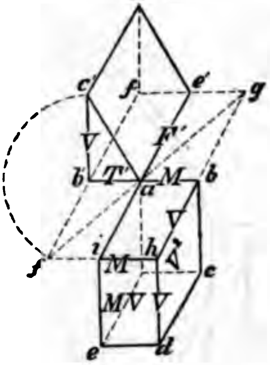

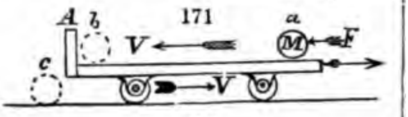

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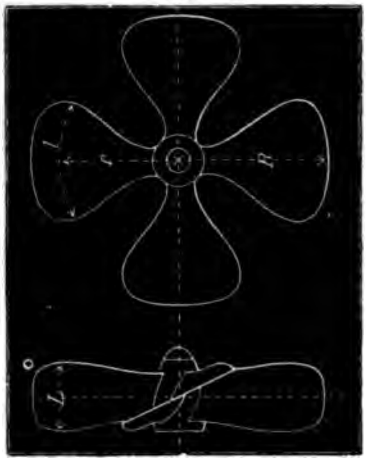

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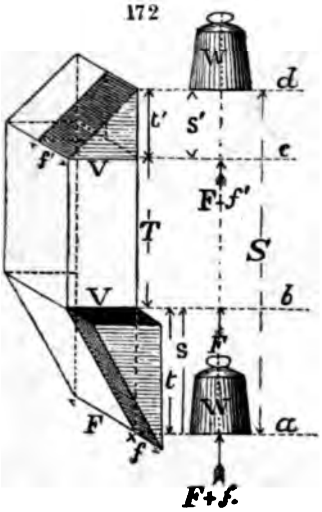

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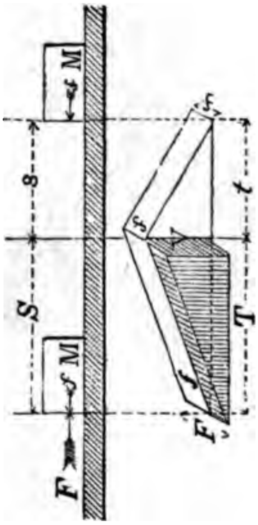

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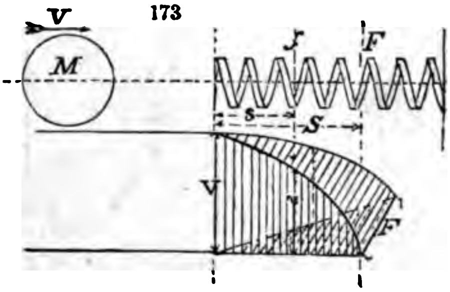

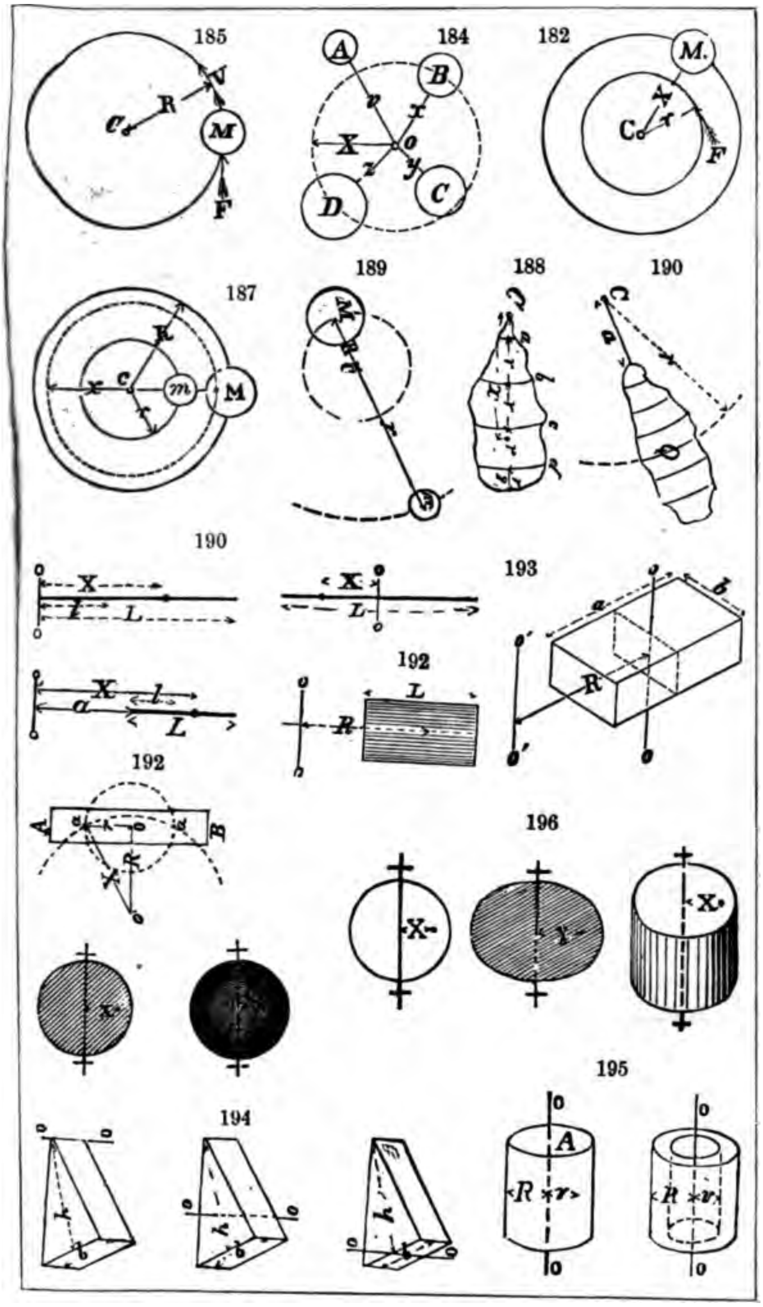
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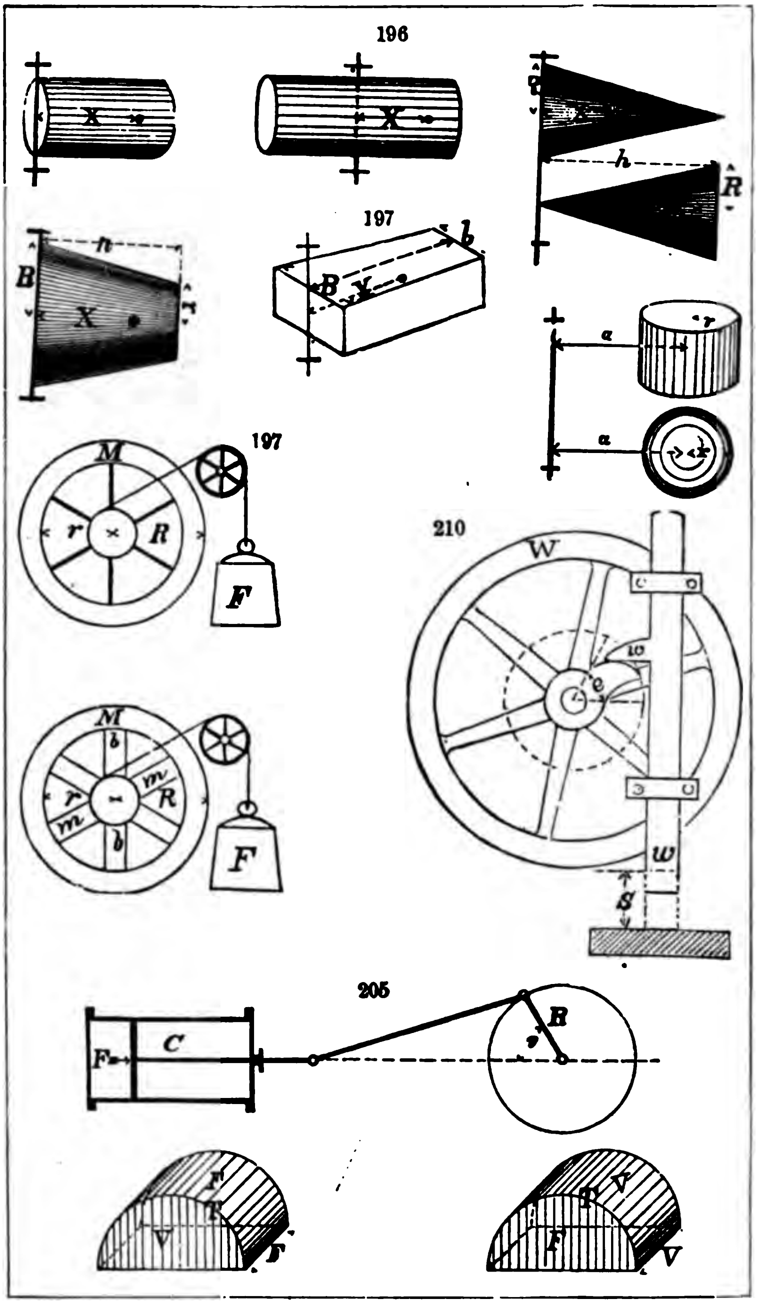
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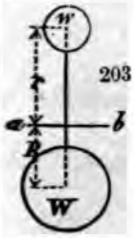

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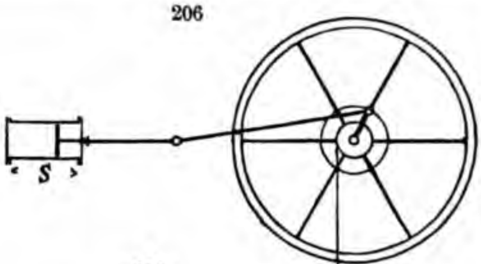

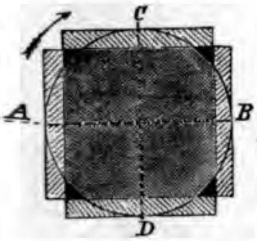

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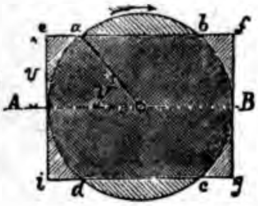

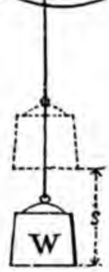

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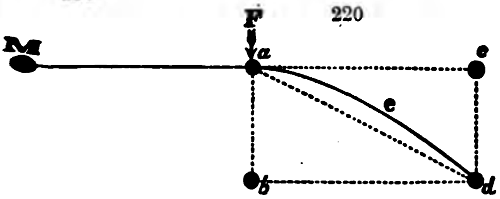

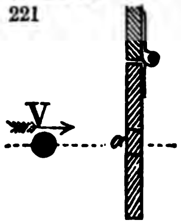

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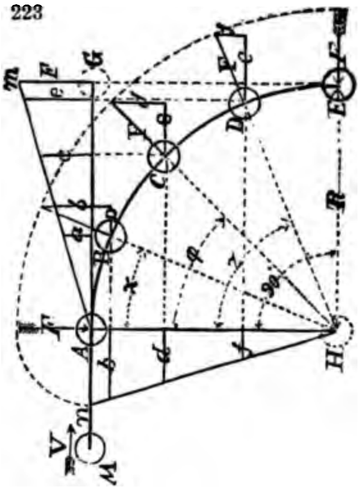

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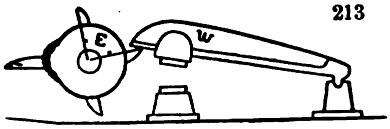

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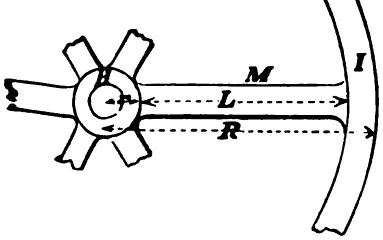

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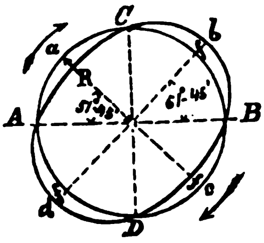

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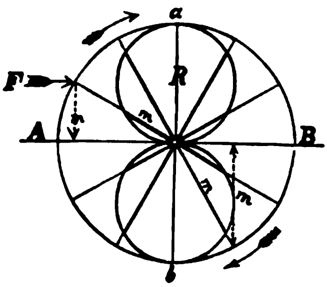

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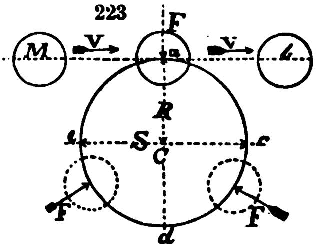

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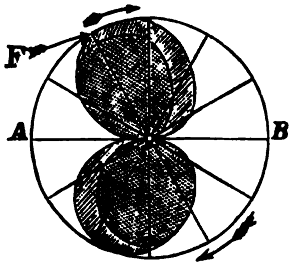

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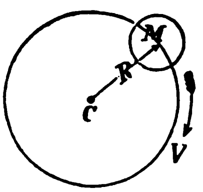

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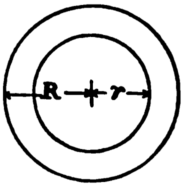

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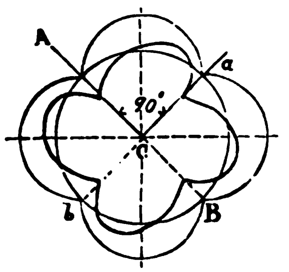

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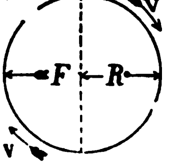

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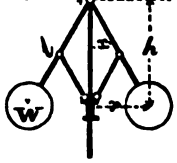

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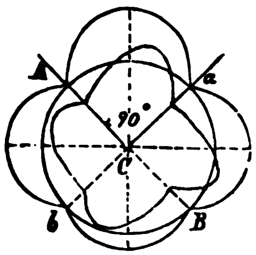

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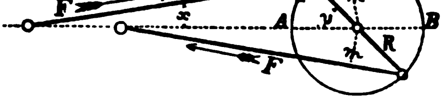

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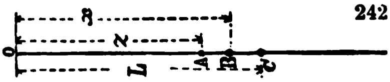

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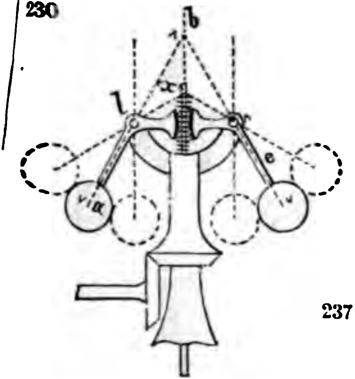

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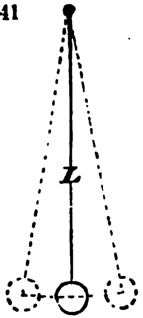

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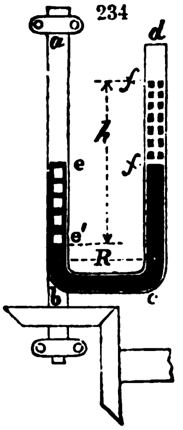

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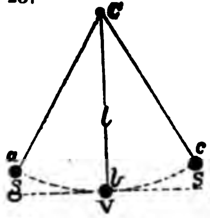

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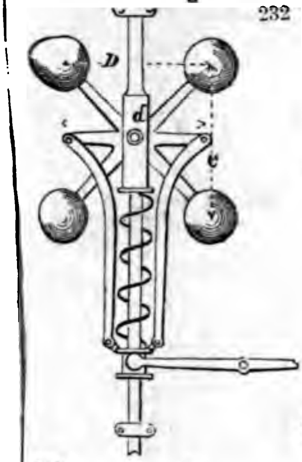

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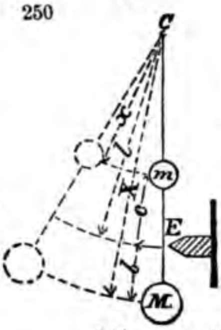

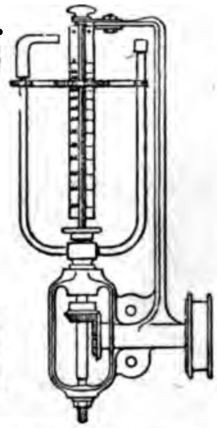

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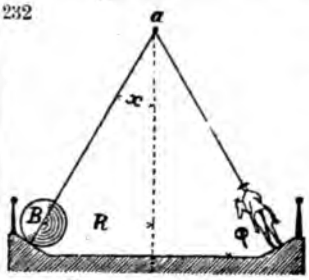

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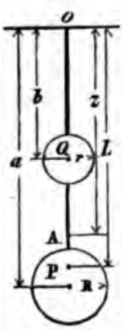

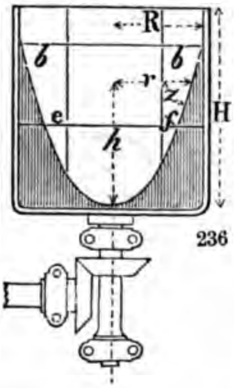

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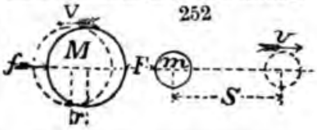

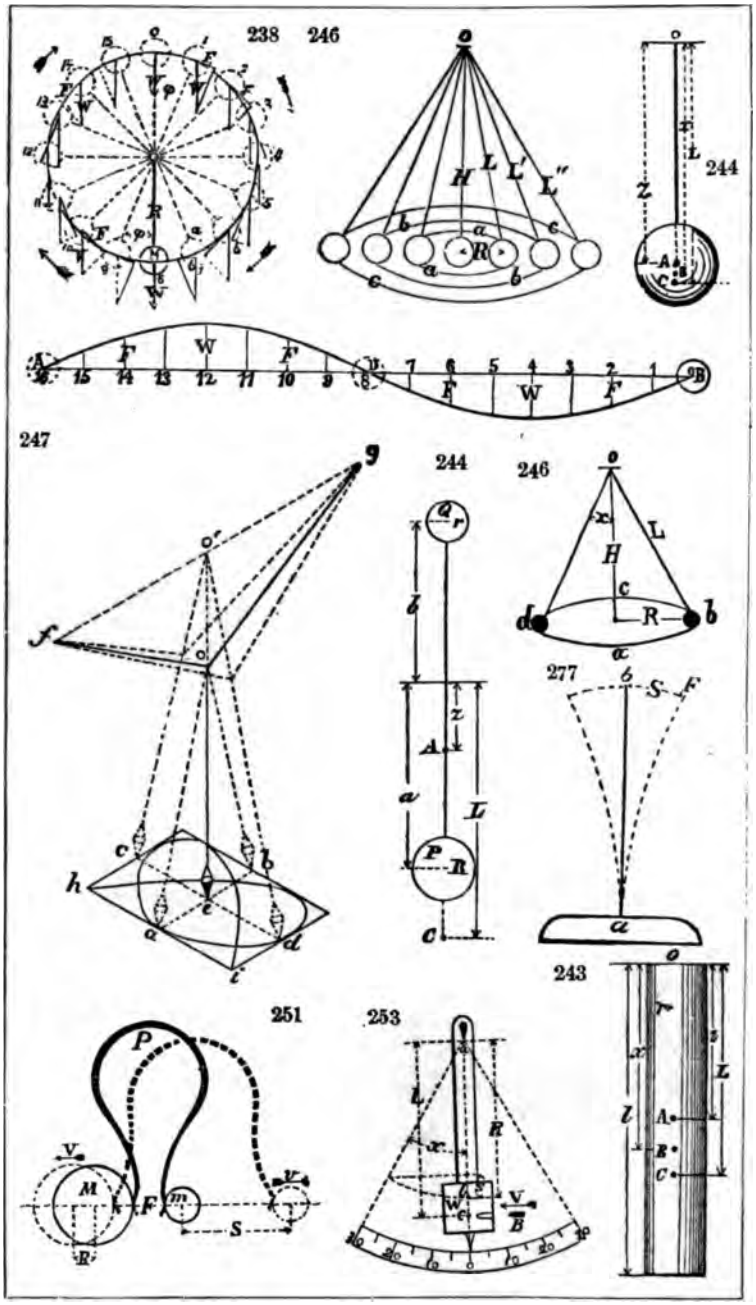
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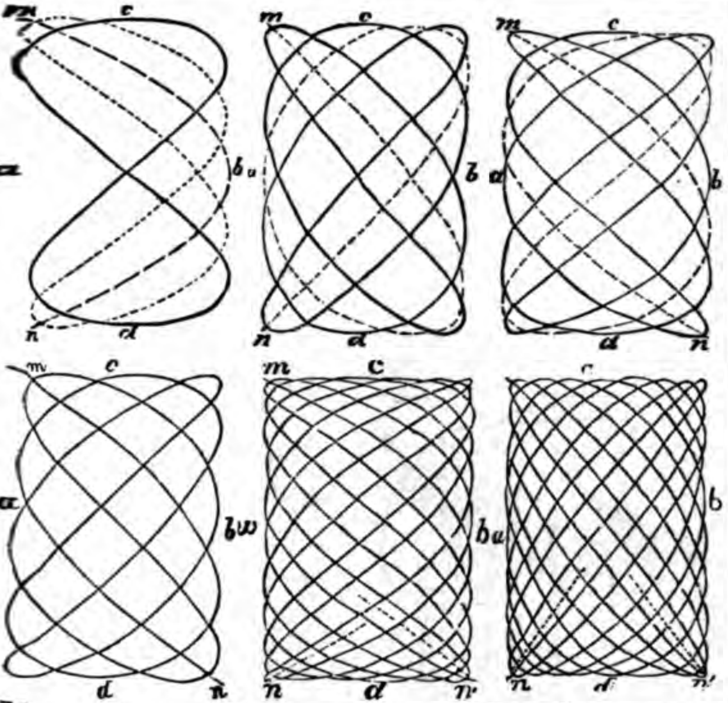

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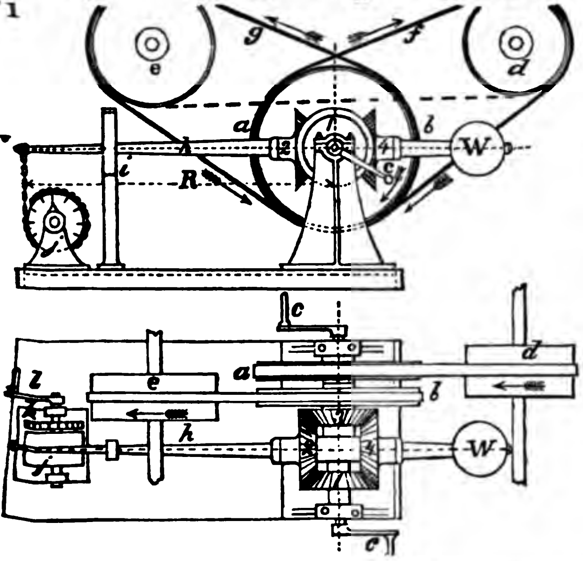

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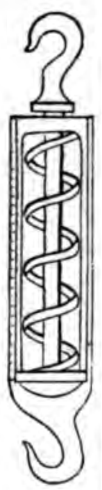

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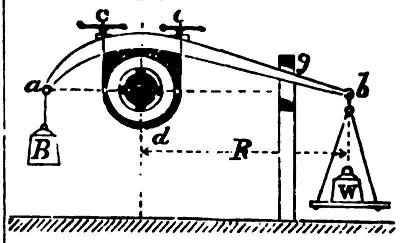

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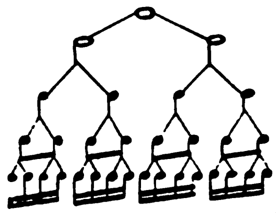

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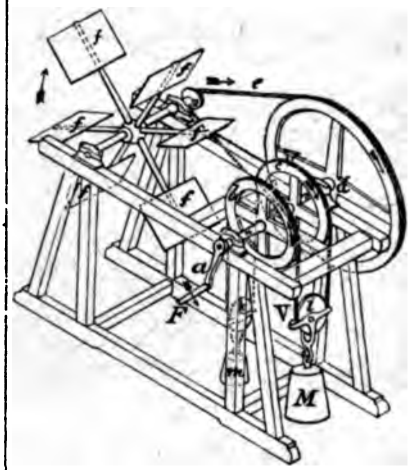

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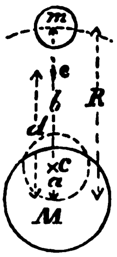

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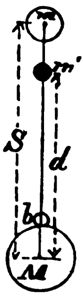

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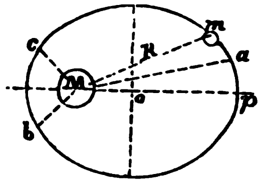

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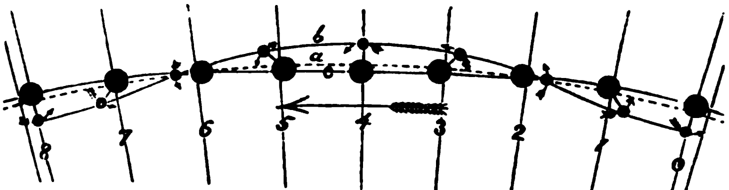

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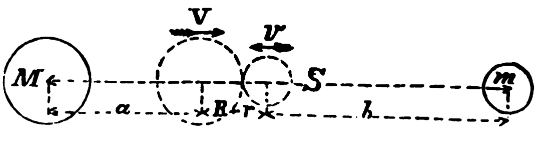

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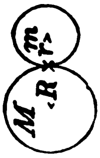

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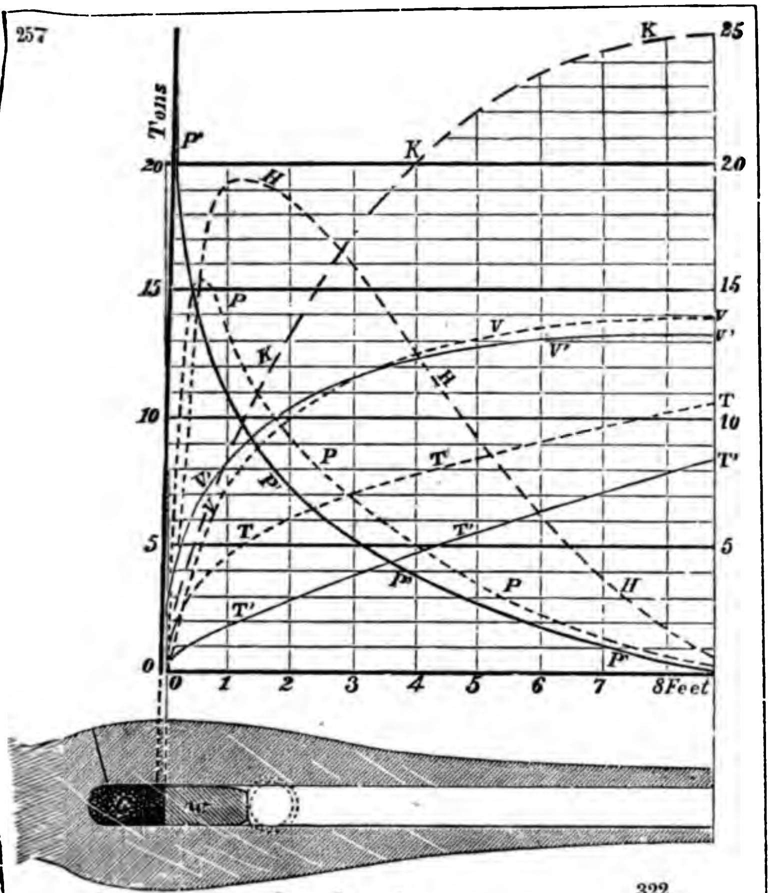

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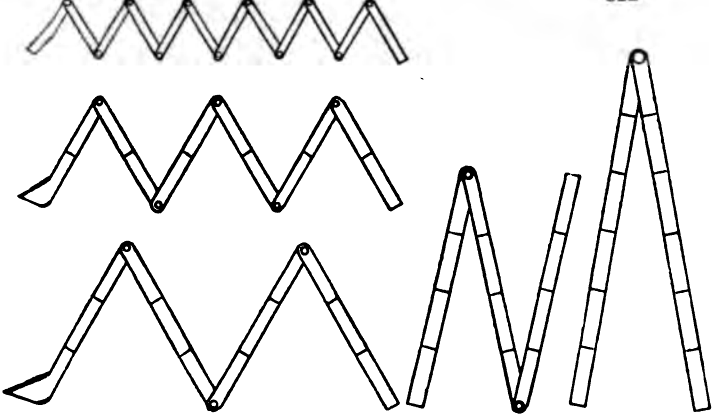

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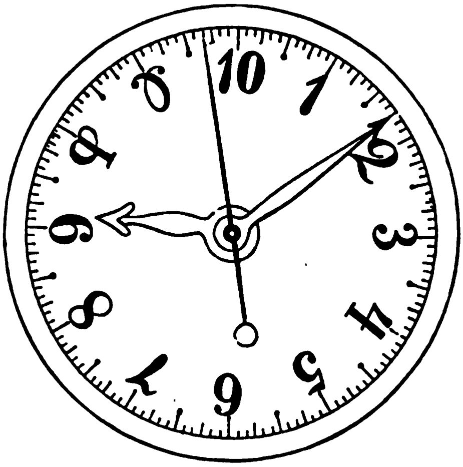

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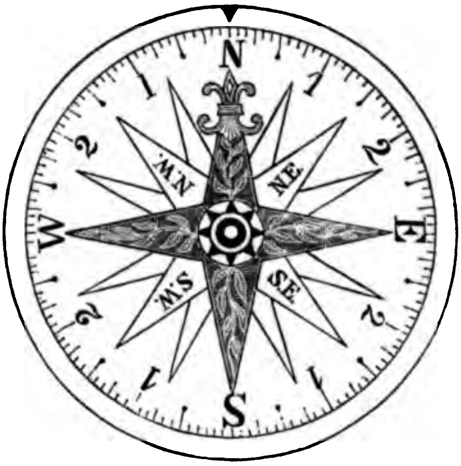

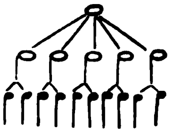

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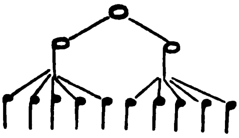

THE METHODS

OF

Testing Steam Engines;

WITH A DESCRIPTION OF THE TRIALS OF

BLAKE'S PATENT CIRCULATING PUMPS,

On the U. S. S. "Tennessee."

By GEO. P. HUNT, P. A. Eng., U. S. Navy,

AND

THERON SKEEL, C. E., Morgan Iron Works, N. Y.

PHILADELPHIA:
Reprinted from the *Journal of the Franklin Institute*, for
December, 1874.

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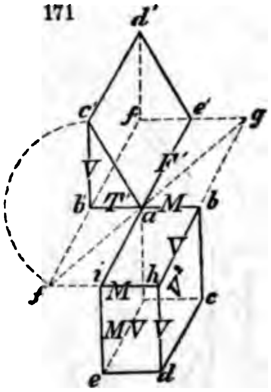

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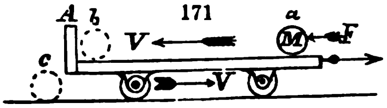

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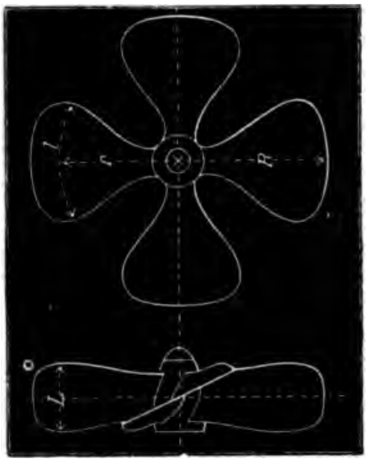

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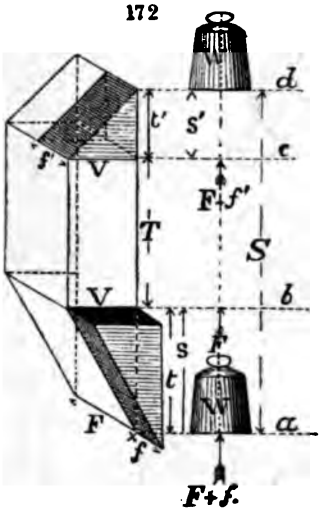

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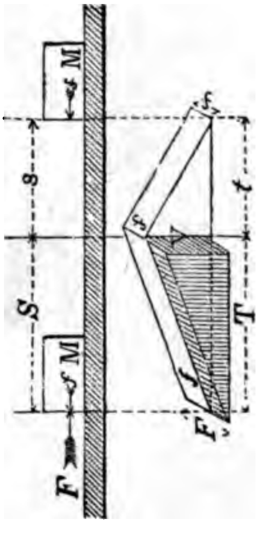

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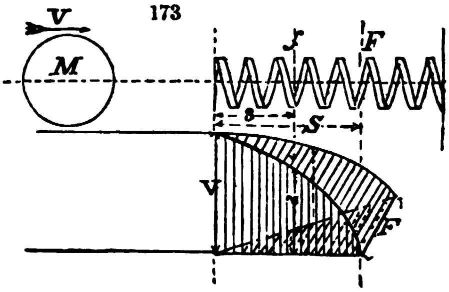

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The Methods of Testing Steam Engines;

With a Description of the Trials of the Circulating Pumps on the U. S. S. "Tennessee."

BY GEO. P. HUNT, P. A. ENG. U. S. NAVY,

AND

THERON SKEEL, C. E., MORGAN IRON WORKS, NEW YORK.

It has been generally customary, in making experiments on steam engines in order to determine their economy, to measure the amount of coal consumed in performing a certain amount of work. These measurements give the commercial economy of the machine.

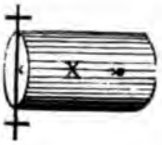
So long as all the machines compared are of the same design and dimensions, and the coal used is of the same kind and quality, and the pressure of the steam, the degree of vacuum, the rate of expansion, the temperature of the atmosphere, and all other circumstances are the same, it may be inferred that any difference in the economy is the result of some imperfection in the machine itself.

Or if there is a variation in one particular only, as, for example, in the pressure of the steam, the difference may be fairly assumed to be due to that variation; but if there are several variations at the same time, as, for instance, different kinds of engines or boilers, and different steam pressures, when there is any gain or loss of economy it is impossible to decide to which of the variations the change is due.

It may be that if a poorer economy shows in the case where there is used the higher steam pressure and greater expansion, then the power which was gained by the high steam pressure and great expansion, was lost, together with something more, in the increased condensation and leakage; or that where in addition there are also used different kinds of boilers in the two cases, that the power which was gained in the engine was lost in the boiler, or the reverse, leaving the final result the same.

Any differences in the kinds of coal used, or in the skill of the firemen, blend themselves inseparably with the other variations, and are indistinguishable from them in the final result.

An exhaustive series of experiments on all of even the important points of variation in modern steam enginery, *separately*, there only



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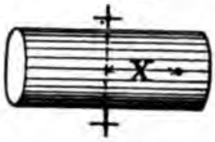

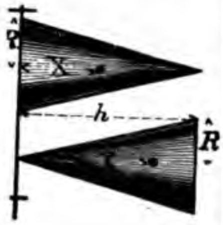

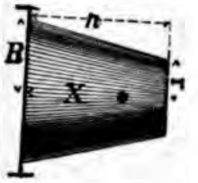

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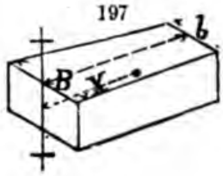

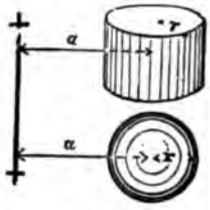

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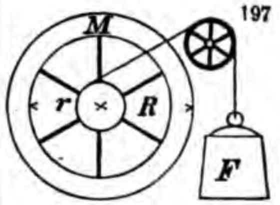

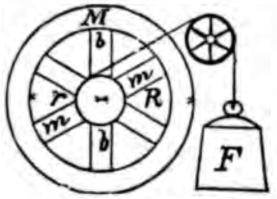

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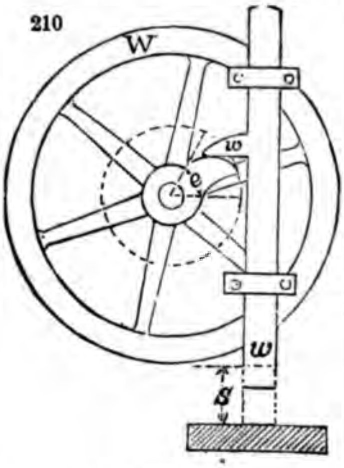

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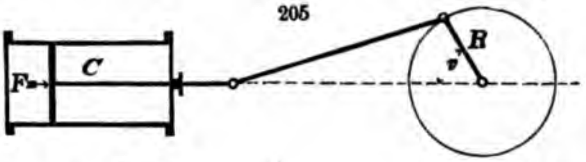

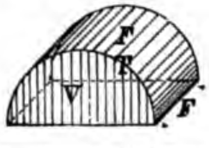

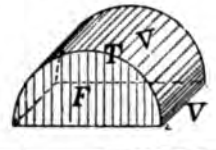

ble is first developed as heat by the burning of the coal; a portion of this heat is utilized in changing the water into steam, the balance being wasted either in radiation or by being carried off in the hot gases through the chimney. A part of the steam formed is applied to move the piston, the balance being wasted by condensation against the sides of the pipes and cylinders, and by leakage past the piston or valves into the condenser. Only a small portion of the total force contained in the steam that is applied to move the piston is utilized, the balance escaping with the exhaust steam into the condenser. Of the force that is utilized in the cylinder only a portion performs any external work, the balance being absorbed in overcoming the back pressure and by the friction of the machine itself. Of the remaining small portion that may be applied to the screw another part is wasted in overcoming its useless resistances, and only the balance used to propel the ship.

The following figures represent approximately the *supposed* distribution of the total force in the best examples. No account is taken in them of the coal that is consumed in the various ways on board ship other than those mentioned, as, for instance, in getting up steam, or steam used to work pumps, for steam lost through the safety-valves, for heat lost in blowing off, or remaining in the furnaces after the vessel has arrived in port. These and other causes usually add at least ten per cent. to the consumption, leaving the force utilized about *six* per cent. of the total force expended in the coal. The cost of an indicated horse power by the figures would be 2½ lbs. of coal per hour, nearly.

		PER CENT.
Total heat in one hundred lbs. of anthracite combustible, in units of heat, . . .	1,400,000	
Deduct heat equivalent to weight of ashes, .	200,000	
Total heat in one hundred lbs. of anthracite coal,	1,200,000	100
Carried off by hot gases in chimney, . .	200,000	16⅔
Available to produce steam, . . .	1,000,000	83⅓
Lost by leakage and condensation, . .	200,000	16⅔
Available to perform work in cylinder, .	800,000	66⅔
Escaped with steam into condenser, . .	660,000	55
Transformed into work, . . .	140,000	11⅔
Absorbed in overcoming resistance of engine and load, ...	40,000	3⅓

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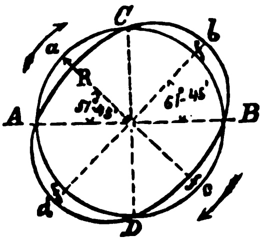

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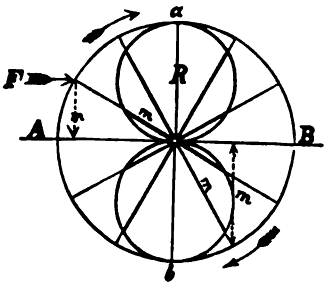

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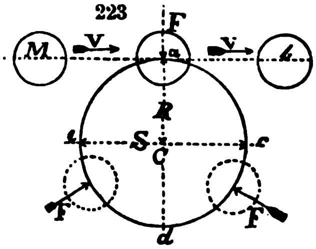

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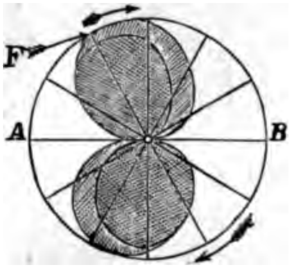

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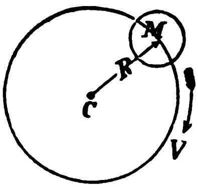

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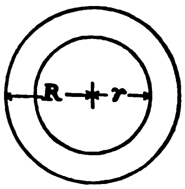

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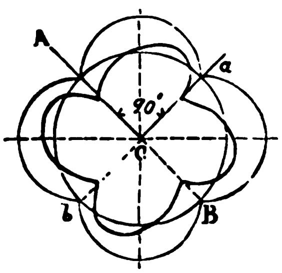

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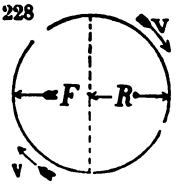

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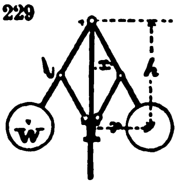

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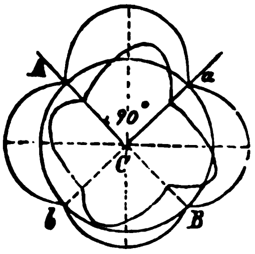

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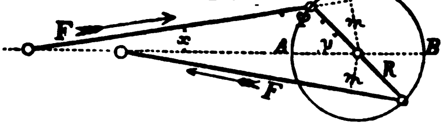

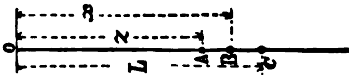

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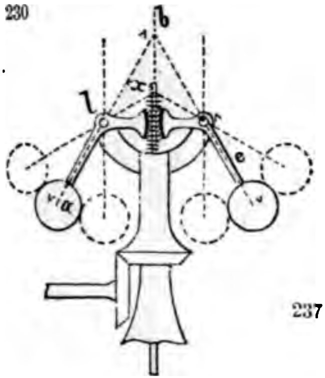

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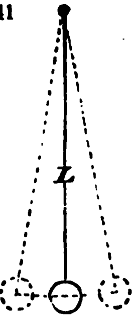

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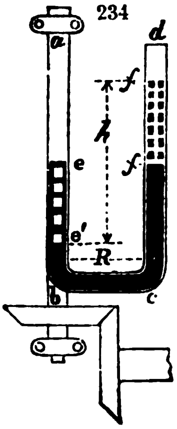

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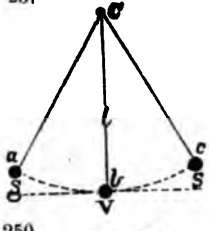

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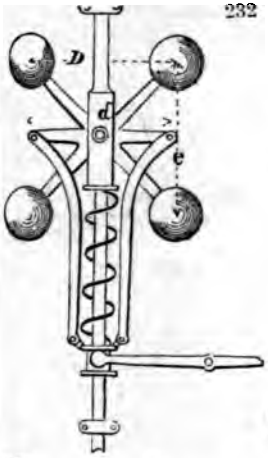

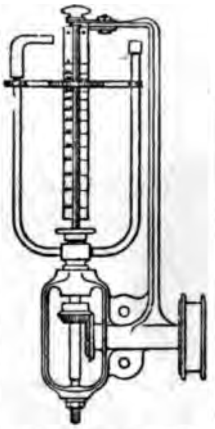

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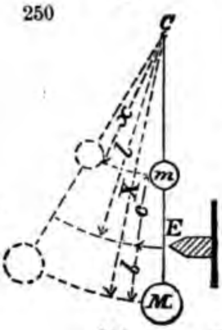

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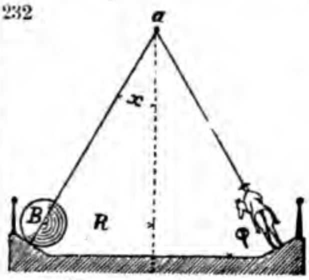

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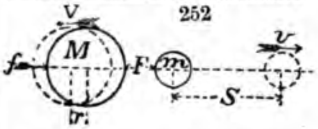

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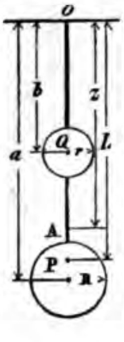

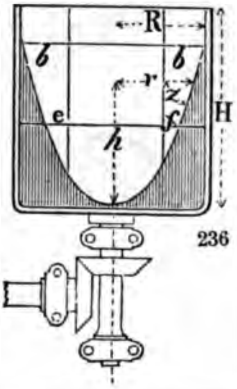

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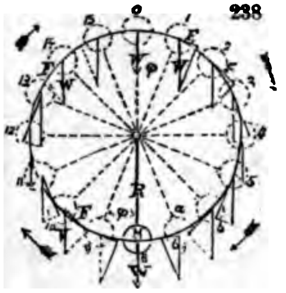

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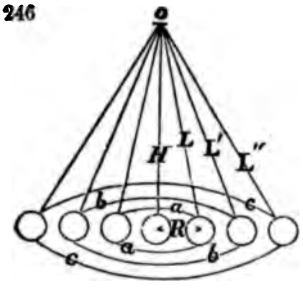

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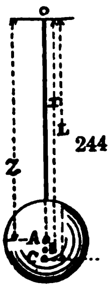

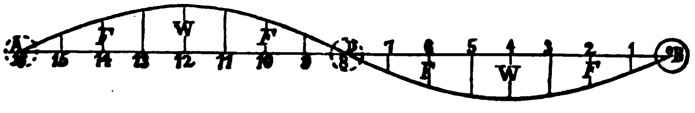

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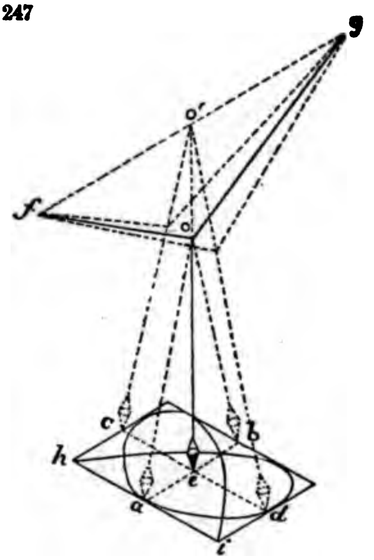

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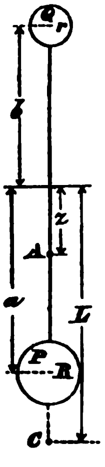

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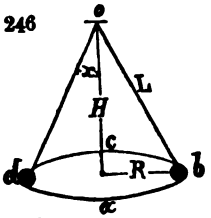

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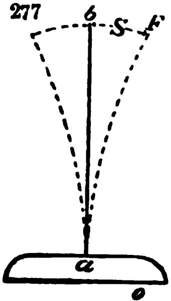

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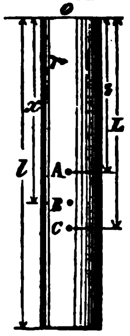

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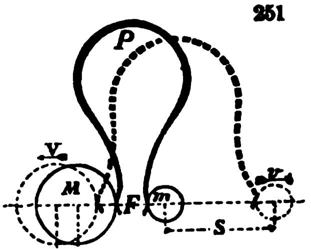

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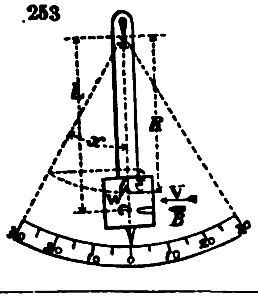

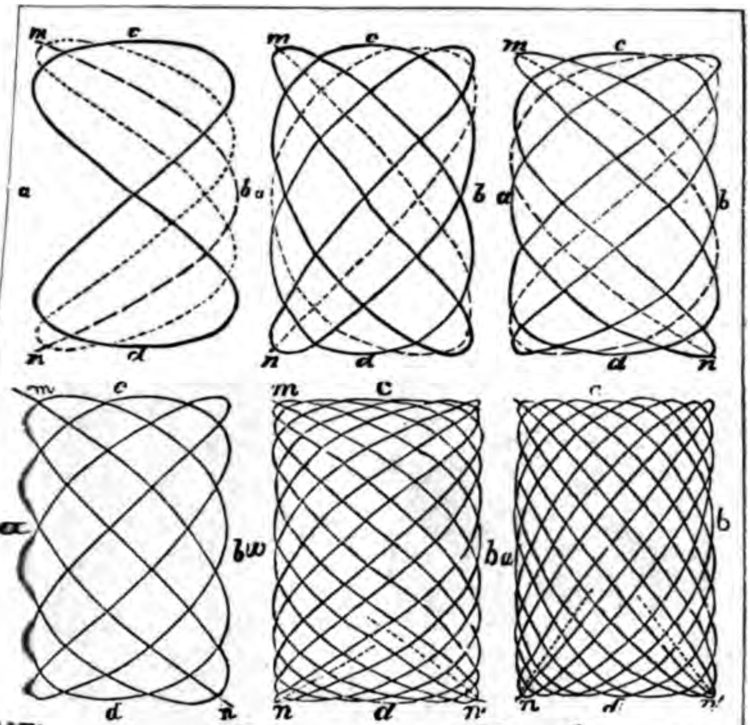

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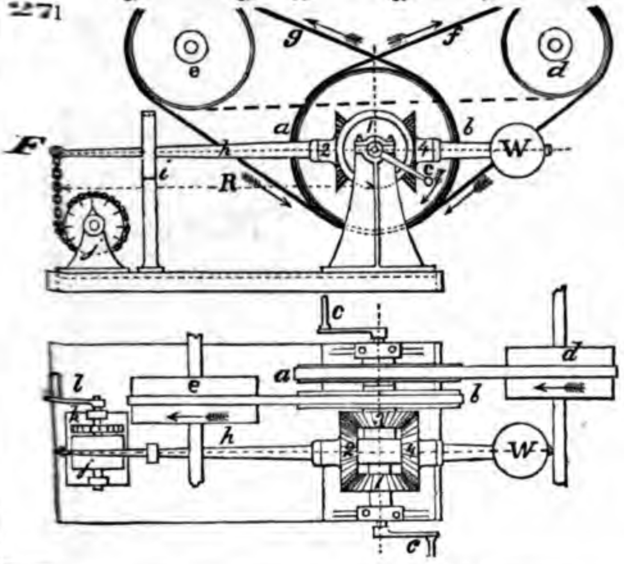

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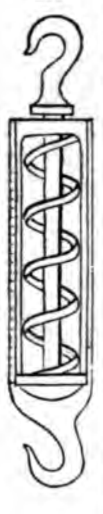

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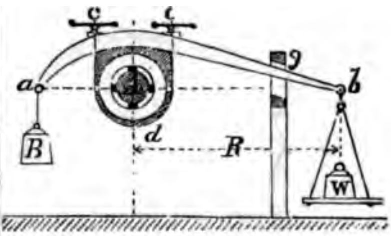

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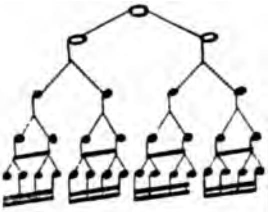

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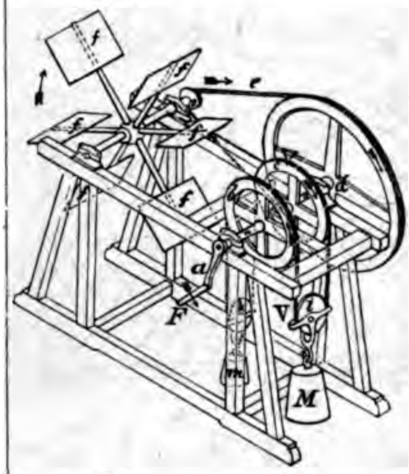

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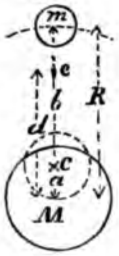

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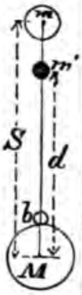

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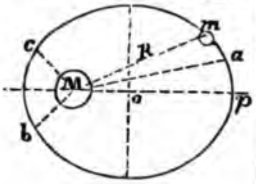

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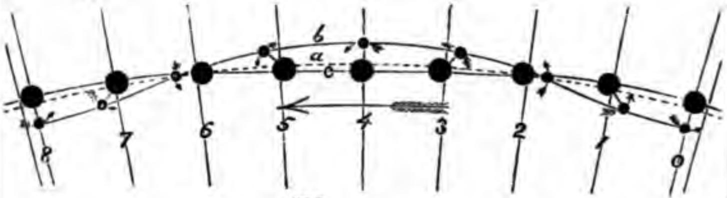

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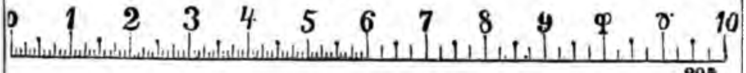

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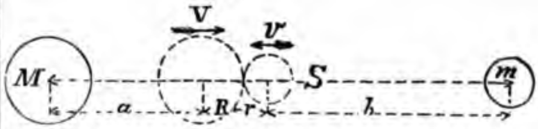
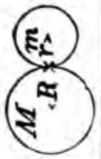




The tappet rod passes through the heads of both steam and water cylinders, is moved in one direction on being struck by the steam piston just before reaching the end of the stroke, and the reverse when struck by the water piston. This arrangement allows the distance between the pump and the steam cylinder heads to be reduced to only that necessary to draw back the glands for packing. When the valve is moved by any tappet on the piston rod, the distance between the cylinder heads must be at least the length of the glands, plus the length of the stroke.

The tappet rod is connected through a vibrating lever and stem to a casting which combines both the auxiliary valve and a movable seat for the main steam valve. The main valve is an ordinary "D" valve sliding upon the movable seat, and held between two shoulders of a supplementary piston or plunger.

The ends of the supplementary piston or plunger are fitted in their respective cylinders, which are cast in one piece with the main valve-chest, the outer ends of these cylinders being connected with openings under the auxiliary valve by little ports cast in the chest. These small ports lead from the auxiliary valve-seat towards each end of the supplementary cylinder, and are divided so as to enter at two different points, one through the head, and the other some distance from it, this last being covered by a piece of sheet brass acting as a valve which allows steam to enter the cylinder but opposes its exit.

In order to understand the action of the valve, consider the case when the piston is moving to the right. The movable seat or auxiliary valve having been previously moved to the left, the former partly closing the ports in the valve-seat, the plunger and main valve will have been moved to the right, thus admitting steam to the left of the piston, and releasing it from the right. The piston moving steadily toward the right will, when near the end of its stroke, strike the tappet rod, moving it, and with it the auxiliary valve first into position shown in Fig. 4. The ports to either end of the supplementary cylinders are closed, but the main steam port to the left and the exhaust port to the right end of the main cylinder are yet open, the main valve being still at the extreme right. The main piston being still exposed to the steam pressure continues on towards the right, and moves the auxiliary valve with it until the steam communication is opened by the small ports to the right end of the supplementary cylinder, and at the same time the steam in the other end is released. The full pressure of steam then acts on the plunger or supplementary piston to move the main valve to the left and admits steam to the right-hand end of the steam cylinder. At this instant the main piston is within a fraction of the end of its stroke, but may continue to move toward the end until the steam has had time to overcome the inertia of the plunger. When this has been overcome it moves rapidly to the left until the left end of the plunger has closed the branch port of the cylinder, and the other branch in the head being already closed by the brass valve the steam remaining in the cylinder cannot escape, and the supplementary piston is gradually brought to rest by the accumulating press between the piston and the head. During this interval the main piston commences its return stroke. So far the action is similar to the ordinary auxiliary valve motion.

In all steam pumps which have only this motion it will happen that when the pump is running very rapidly, as when it sucks air, that the piston will move past the point where the auxiliary valve admits steam to the plunger, and will strike the head before the steam has time to act upon the valves. But in this pump if the main piston continues towards the head it must draw with it the movable seat, until the right-hand port passes the outer edge of the main valve, opening the port to the steam, and the left-hand port passes the inner edge opening the left end of the cylinder to exhaust. Under the above circumstances, the main piston will make a return stroke even though the supplementary piston and main valve should not have time to move at all.

Independent circulating pumps for marine engines are rapidly gaining favor; being independent of the main engines they can be run at any desirable speed, and as they are generally in duplicate, one can be repaired if necessary, while the other is doing duty.

In addition, they furnish a great safeguard against foundering at sea in case of accident to the main engines. If the pumps were attached to the main engines, the same weight of water could be delivered overboard if the engines could be run at the proper speed, but it must be remembered that it takes the whole power of the boilers to run the engines at the ordinary speed, and that their speed cannot be increased in an emergency, but oftentimes by reducing the speed of

Fig. 1 shows a section and elevation of the pump.

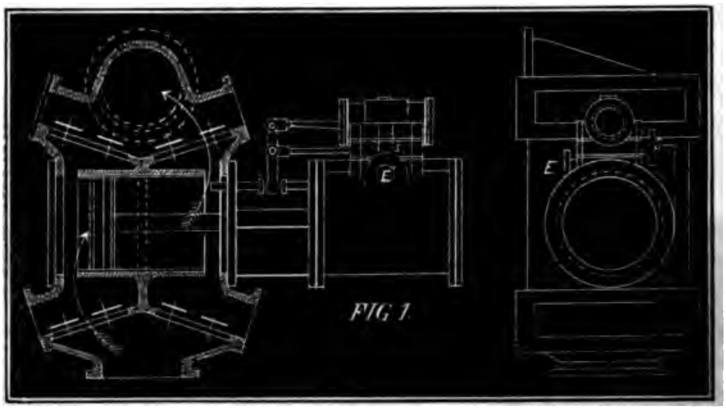


FIG 1.

There are two of these pumps used for circulating the water through the condenser. Each pump has a separate suction pipe, drawing water through a strainer containing 2000 ½-inch holes, in the bilge of the ship, thence to a Kingston valve, and through 15 feet of 15-in. copper pipe, to pumps, and delivering through 13 feet of 15-inch copper pipe to top of condenser. Here the water from both pumps combines and passes four times through nests of condenser tubes, each nest containing 1978 tubes, ½ inch internal diameter and 7 feet 3½ inches long, and thence through two copper pipes, each 15 inches diameter and 25 feet long, to outboard delivery valves, 24 inches below the surface of the water outside. For the purpose of this experiment a 15-inch copper pipe was bolted to each outboard delivery valve, to carry the water up to a tank, where it could be measured. This pipe had at the lower end a right angle bend of a central radius equal 14 inches, and at the upper end a return bend or goose-neck of the same radius.

The height of the centre of the goose-neck above the surface of the water was 11 feet. An additional length of leather pipe, 4 feet long, was fastened to the goose-neck, in order to carry the stream below the surface of the water in the tank, as it was found that if the stream fell through the air into the tank, so much air would be carried down with it as to render it impossible to know how high the surface of the water in the tank was. When the stream was protected the surface was clear and smooth. It was proposed to measure the water by allowing it to flow through a number of orifices in the bottom of the tank, each orifice being small enough to allow the water delivered by it to be measured separately at any instant during the experiment; the sum of all the deliveries, or the average of a sufficient number to determine a mean multiplied by the number of orifices, being the amount of water discharged.

Fig. 2 shows a section through the condenser and side of the ship; the arrows showing the course of the water.

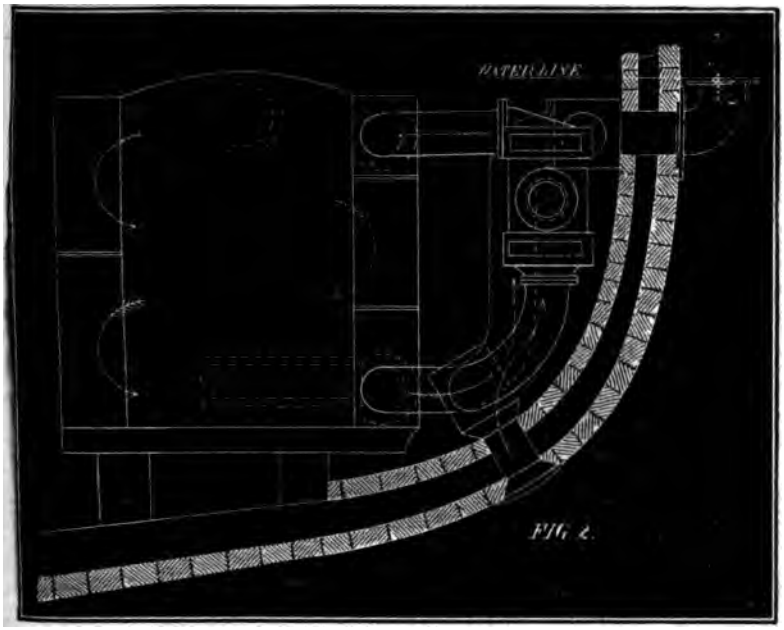


FIG. 2.

There was a separate tank for each outboard delivery, of the following dimensions: diameter, 48 inches; height, 72 inches; thickness, ¼ inch.

A hole, 24 inches in diameter, was cut in the bottom, and a composition plate, planed 1 inch thick and 28 inches diameter, was bolted upon the under side. There were drilled in this plate 55 holes, each hole being 1⅛ inches diameter, and beveled out on the upper side, the depth of the bevel being ¼ inch and the angle 30° from the vertical side of the hole. The average distance between the centre of these holes was 3½ inches.

During the experiment a portion of the holes was plugged up with soft pine plugs. During the experiment the pump worked under the additional load due to the 11 feet head on the standing pipe and the friction of the sides and bends—more than would be required when in regular use at sea.

Fig. 3 shows the arrangement of the tank in reference to the water and side of the ship, and the method of supporting the platform and measuring barrel.

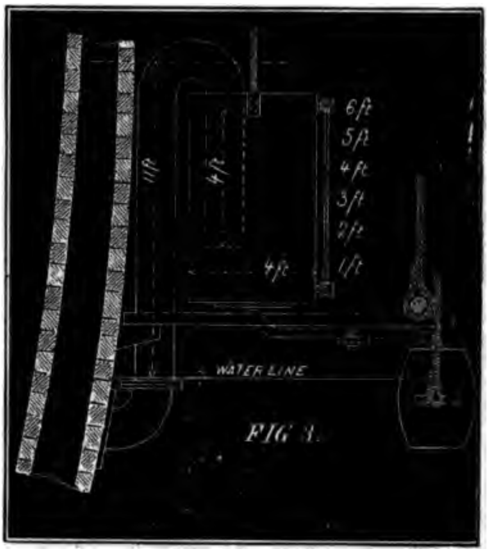


FIG 3.

It will be seen that the two circulating pumps act entirely as meters of the best construction, for they are sufficiently far below the surface of the water outside the ship to be filled to overflowing at every stroke and the entire cylinder full of water must be forced through the condenser on the return stroke.

If the rate of these pumps as meters could be determined at various velocities, the volume of water which they were delivering at any time, could be computed.

The following is a description of the apparatus used, and the results obtained in the experiment made previously to the trial of the ship's engines, which has not yet taken place.

It is expected that the trial will take place so soon as the ship comes out of the dock, where she is now receiving new decks and general repairs.

The following experiments were made with the pumps:

1st. To determine the volume of water that would be discharged through the plate in the bottom of the tank, at various heads, and with various numbers of the orifices plugged up.

2d. To determine the volume of water thrown by the pump at various velocities, and the power required.

To determine the amount of water discharged, the pump was run at a velocity required to maintain the desired head in the tank, and the water discharged through one orifice was received in an oil barrel, through a 3-inch iron pipe, one end of the pipe being curved up on a radius of 12 inches and adjusted under an orifice, so that the whole stream would fall directly into it; the other end being curved down to discharge into the barrel. The total length of pipe was 9 feet, and it was so supported that it could be adjusted under any orifice and made fast.

The spaces between the streams were large enough to allow the observer to notice that the whole stream was falling into the pipe, even when under the central orifice.

The barrel to receive the water, the contents having been carefully weighed and measured, was hung so that it could be swung under the end of the pipe at the instant desired, and, when full, dumped.

The time occupied in filling, and the mean head during the interval, were noted, and the experiment repeated a number of times. The position of the pipe was then changed to come under another orifice, and the experiment repeated, and so on until the mean discharge of all the orifices, at various heads was determined.

The temperature of the sea water during these experiments was 74°, and the saturation $\frac{1/4}{32}$ (July 8th, 9th, 10th, 11th).

The barrel contained 6·357 cubic feet.

It was found that when the depth of water over the plate was more than 3 feet, that there was no perceptible difference on the discharge of orifices in various parts of the plate; but that when the head became less than 3 feet, the discharge varied in different orifices, and at different times in the same orifice, under the same head.

This was true, whether all the 55 holes were open, or whether a portion of them were plugged. There could not be detected any difference in the flow, with a head of more than 3 feet, from a difference in the arrangement of the open and closed holes.

The following are the mean results of 49 experiments with a head greater than 8 feet:

Head of water above plate, in inches.	Cubic feet discharged by each orifice per second.
72·154	·1059
52·660	·0900
41·050	·0796

Fifty-four experiments on less heads than these gave results varying among themselves from zero to twenty-five per cent., and are therefore rejected.

The amount of water discharged from the same orifice at different heads should vary, if there were no causes of disturbance, as the square root of the heads.

The following comparison of the amount discharged actually and computed for the last two cases, by a comparison of the square root of the heads with the amount delivered in the first case, shows that the discharge does vary as the square root of the head, as the differences are within the errors of observation:

Head in inches.	Discharge by Experiment.	By Comparison.
72·154	·1059	———
52·660	·0900	·09019
41·050	·0796	·07964

The coefficient of contraction being the ratio of volume of water actually discharged to that represented by the area of the orifice multiplied by the theoretical velocity, is

$$C = \cdot 7776.$$

The following table shows the number of cubic feet which will be discharged by each orifice during one hour at various heads, computed from experiments, by a comparison of the square root of the heads. If no opportunity should offer during the trial of the engines to test the capacity of the orifices, it will only be necessary to note the head of water in the tank, and to multiply the corresponding discharge from the table by the number of orifices open, in order to obtain the volume of water discharged per hour at any given instant.

The mean of these volumes (not the volumes corresponding to the mean head) will give the mean discharge of the pump for any number of observations.

The only apparent cause of error will be a change in the density of the water, either from more or less salt, or from a change of temperature; but the errors from these causes will probably be inappreciable.

NUMBER *of cubic feet which will be discharged in one hour from a single orifice at various heads, computed from experiment by a comparison of the square root of the heads.*

Head in inches.	Discharge.	Head in inches.	Discharge.
72	380·8	52	323·7
71	378·2	51	320·6
70	375·5	50	317·4
69	372·8	49	314·2
68	370·1	48	311·0
67	367·4	47	307·8
66	364·6	46	304·5
65	361·9	45	301·1
64	359·1	44	297·7
63	356·2	43	294·3
62	353·5	42	290·9
61	350·6	41	287·4
60	347·7	40	284·0
59	344·8	39	280·3
58	341·8	38	276·7
57	338·8	37	273·1
56	335·9	36	269·3
55	333·0	35	265·6
54	329·9	34	261·7
53	326·8	33	257·9
52	323·7	32	254·5

At the conclusion of the experiments upon the tanks, a series of experiments were made upon the pumps, to determine the volume of water delivered at various velocities, and the power required to work them.

These experiments were made by running one pump at a velocity necessary to maintain a constant head in the tank of nearly five feet, the engineer changing the throttle a little, in response to signals, when the head of water varied. It was found that the head could be maintained within two inches of that desired.

All the experiments were made with the same head of water in the tank, more or less of the holes being plugged, in order to change th velocity of the pump in the different experiments.

In some of the experiments the pumps were run one hour, but was concluded that as the head and strokes were so nearly constan one half hour was sufficient for the latter portion of them.

The number of strokes was counted every 5 minutes during tl hour trials, and every 2½ minutes during the half hour trials, durin one minute, by a sand glass, which had been tested and found to t correct, and the mean head (when there was any variation) durin the minute noted.

Indicator cards were taken every five minutes during the tri from both the steam and water cylinder of the forward pump.

There were no indicator attachments on the after pump.

The scales of the indicator springs were found by experiment.

The stroke of the forward pump was 18¾ inches.

The stroke of the after pump could not be measured.

The following are the means of the result:

FIRST EXPERIMENT.

Which Pump.	Forward.	After.
Number of strokes,	63·46	64·5
Head of water in tank,	61·115″	60·75″
Number of holes open,	30	30
Cubic feet of water per hour,	10,530	10,572
Nominal volume of pump,	10,930	11,110
Per cent. of do. delivered,	96·4	95·2
Actual volume of pump,	10,510	
Per cent. of do. delivered,	100·2	

SECOND EXPERIMENT.

Which Pump.	Forward.	After.
Number of strokes,	79·643	85·458
Head of water in tank,	59·8″	61·041″
Number of holes open,	40	40
Cubic feet of water per hour,	13,884	14,003
Nominal volume of pump,	13,715	14,720
Per cent. of do. delivered,	101·2	95·3
Actual volume of pump,	13,190	
Per cent. of do. delivered,	105·	

THIRD EXPERIMENT.

Which Pump.	Forward.	After.
Number of strokes,	95·8	99·2
Head of water in tank,	61·″	60·9
Number of holes open,	48	48
Cubic feet of water per hour,	16,828	16,827
Nominal volume of pump,	16,500	17,080
Per cent. of do. delivered,	102·	98·5
Actual volume of pump,	15,870	
Per cent. of do. delivered,	106·2	

It would, at first thought, appear impossible that any pump should deliver more water than the actual piston displacement, but it must be remembered that the conditions of these pumps are materially different from those generally tested.

In place of having to suck the water from a tank below, the pump cylinder is 2½ feet below the surface of the water, which would, if the piston were at rest, fill the barrel, and rise 2½ feet above.

The maximum velocity of the water in the suction pipe is less than 4 feet per second, while the velocity due to a head of 2½ feet is more than 14 feet, leaving a margin of 10 feet velocity corresponding to a head of more than 1½ feet, tending to overflow the pump barrel.

This would account for an amount of water equal to the full displacement of the piston, for it will be seen hereafter that the head necessary to overcome the resistance of the valves and pipes is less than this difference.

To account for the excess of water delivered another cause appears. The total length of all pipes from the sea to the pump, and thence through the condenser and overboard, is more than 70 feet. These pipes must be filled with a solid column of water, for there are no air vessels on the pump, and there can be no air in the water, except that drawn in through the Kingston valve in the bilge, 20 feet below the surface.

The mean velocity of water in these pipes, at 100 strokes, is more than 3 feet per second.

When the pump piston has its maximum velocity it is pushing this column of water, but when it reaches the end of its stroke and suddenly stops, hesitating an instant before commencing a return stroke, the long column of water cannot be instantly stopped without bursting all the pipes, but must, as in a hydraulic ram, continue in motion until its momentum is exhausted.

The velocity of 3 feet per second would carry it up about 1½ inches in the standing pipe, if the piston should hesitate long enough.

The total travel of the water might be

$$18\tfrac{3}{4}'' + 1\tfrac{1}{2}'',$$

and the per cent. of piston displacement delivered

$$\frac{18\frac{3}{4}+1\frac{1}{2}}{18\frac{3}{4}}=108$$

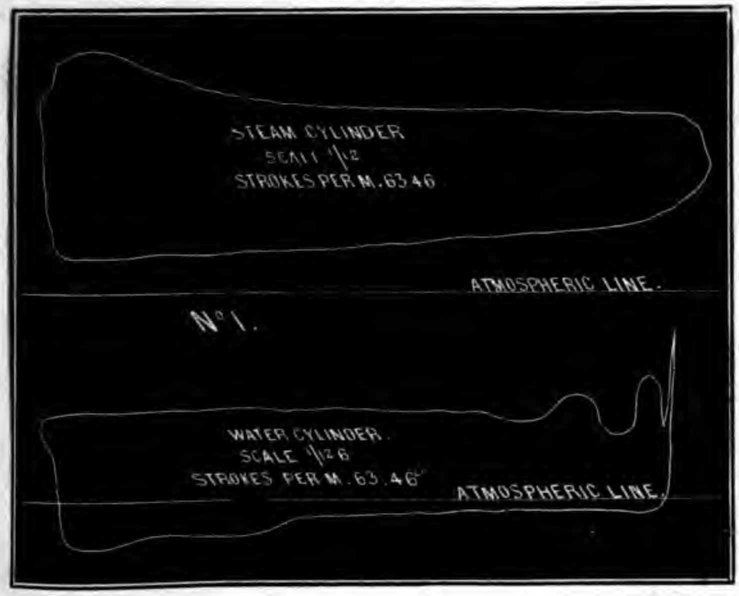
The maximum excess would be, at this speed, 8 per cent., which would be reduced by the resistance of the passages.

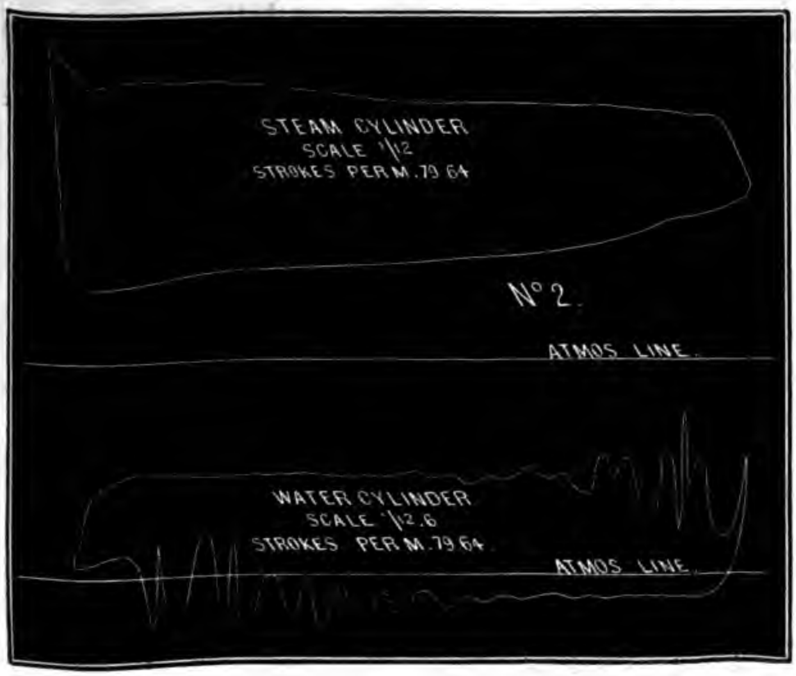
There can be no gain of efficiency from this cause, for although a portion of the water has gone through the pump without effort, when the piston commences its return stroke it will press on the water at rest, or nearly so, which must be set in motion at the expense of the steam.

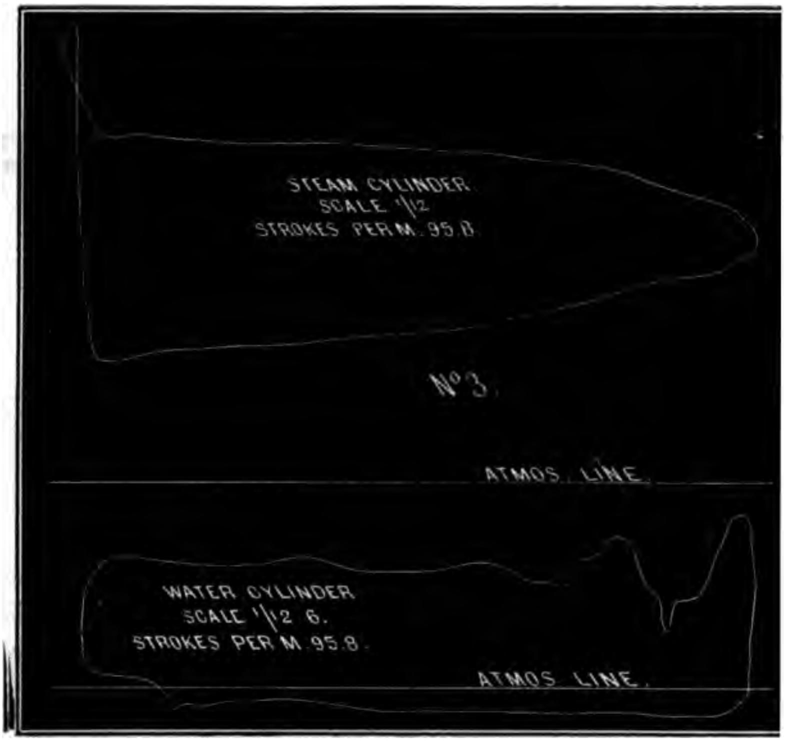
The shape of the indicator cards taken from the water cylinder appears to indicate that, during the first part of the suction stroke, the water was pressing on the piston, as explained above, and that the portion of the stroke through which that action lasts, increases as the pump runs faster, corroborating the measurements and foregoing theory.

The results computed from the indicator cards taken from the forward pump (copies of which are annexed to this paper), are as follows:

Number of strokes, . . .	63·46	79·64	95·8
Steam, mean pressure, . . .	8·6	9·72	10·62
" back " . . .	2·77	6·24	9·34
" total " . . .	11·37	15·96	19·96
Water, mean pressure, . . .	7·118	7·673	8·83
Pressure necessary to work pump, steam pressure less water pressure, . .	1·482	2·049	1·78
	Mean	1·77	
Actual horse-power (one pump),	6·5	11·2	14·7
Actual horse-power at reduced head (one pump),	2·46	4·86	7·1


STEAM CYLINDER
SCALE 1/12
STROKES PER M. 63.46
ATMOSPHERIC LINE.
N° 1.
WATER CYLINDER.
SCALE 1/12.6
STROKES PER M. 63.46
ATMOSPHERIC LINE.


STEAM CYLINDER
SCALE 1/12
STROKES PER M. 79.64
N° 2.
ATMOS. LINE.
WATER CYLINDER
SCALE 1/12.6
STROKES PER M. 79.64.
ATMOS. LINE.



APPENDIX.

The following computation of the head in feet, necessary to for the water through the pipes, valves and condenser tubes at the vel city corresponding to sixty strokes of the pump per minute, ma previous to the experiment, according to the law of hydraulics laid down in Rankine's Civil Engineering, serves to check the acc racy of the experiment, and to show that the power necessary to wo a circulating pump on shipboard can be very approximately co puted when the arrangement of pipes is known:

Assumed velocity of pump, 60 strokes per minute.

	Area in square feet.	Velocity of Wate feet per second
Tubes, . . .	2·698	1·028
Pipes, . . .	1·227	2·241
Pump, . . .	1·767	1·562
Valve ports, . .	1·1875	2·324
Strainer holes, . .	1·474	1·872

The losses of head considered are:

1st. Head necessary to give velocity.
2d. “ “ “ overcome friction.
3d. “ “ “ “ resistance of bends.
4th. “ “ “ “ “ “ valves.

These have the following values:

To give velocity, . . $h = \frac{v^2}{2g}$.

Tubes, . . .	$h =$ ·0602
Pipes, . . .	“ ·2337
Pump barrel, . .	“ ·0758
Valve ports, . .	“ ·1677
Strainer, . . .	“ ·0543
	·5917

To overcome friction $h_2 = F\frac{v^2}{2g}$,

in which F is a factor depending upon the form and material or the passage.

Tubes, . . .	$h^2 =$ ·275840
Pipes, . . .	“ ·089280
Pump barrel, . .	“ ·000222
Valve ports, . .	“ ·001310
Strainer, . .	“ ·004388
	·384040

To overcome resistance in bends, being an amount depending upon number and abruptness of bends, $h_3 = 1·1664$.

To overcome resistance of springs on back of valves.

Area of rubber disc, 50 square inches.
Strength of spring, 45 lbs.
Estimated lift, $\frac{3}{8}$ inch.
Press per square inch, $\frac{9}{10}$ lbs.

Loss of head:

Receiving valve, h_4	1·8
Delivery “	1·8
	3·6

Friction and bends in external pipe:

$$h_5 = \cdot0860$$

Total resistance at 60 strokes:

$$\begin{aligned} h_1 &= \cdot591700 \\ h_2 &= \cdot384040 \\ h_3 &= 1\cdot664000 \\ h_4 &= 3\cdot600000 \\ h_5 &= \cdot086000 \\ \hline & \quad 6\cdot325740 \end{aligned}$$

Total loss from friction at 60 strokes:

$$\begin{aligned} h_1 &= \cdot59170 \\ h_2 &= \cdot38404 \\ h_3 &= 1\cdot66400 \\ h_5 &= \cdot08600 \\ \hline & \quad 2\cdot72574 \end{aligned}$$

Total loss from friction at 63·46 strokes:

$\frac{(63\cdot46)^2}{(60)^2} \times 2\cdot72574 =$	3·049
Resistance of valves, . . .	3·600
Statical head in pipe, . . .	11·000
Computed head equivalent to resistance, .	17·649
Experimental head equivalent to resistance, being mean pressure + height of water above the pump, . . .	16·460
Difference,	1·278
Error of computed resistance in per cent. of actual resistance, . . .	6¾

This error probably arises from the valves not lifting as much as ⅜ inches, and therefore the springs on the backs of the receiving and delivery valves not offering the resistance stated.

4. 75.

Franklin Inst Journal 41: [illegible]

TRIANGULAR BEAMS.

By De Volson WOOD,

Professor of Civil Engineering, University of Michigan.

As I find that the statements of different authors respecting the strength of triangular beams are very conflicting, I propose in this article to make an analytical investigation of the problem, and compare the results with experiment.

The problem may, for convenience, be thus stated:

A triangular prism being supported at its extremeties; it is required to ascertain how great a weight it will sustain at the middle point without fracture.

But as we know that the strength of a beam depends upon its transverse sections, it will only be necessary to investigate the *resistance of a triangular section.*

To introduce the several points which I wish to discuss, I shall make extracts from various authors. I find in Olmstead's Natural Philosophy, p. 153 (or p. 107 of Prof. Snell's edition), the following statement:

"*A triangular beam is twice as strong when resting on its broad base as when resting on its edge.*

I would pass this statement with the remark that the deduction is founded on Galileo's theory, which is known to be false, were it not for the fact that many think that the statement is correct; also that beams made of some kinds of material are stronger in the former than in the latter position, but not for the reasons given by Olmstead.

1. Suppose the beam is made of wood.

The resistance of wood to compression is nearly the same as for extension. If it were the same, the beam would be equally strong in either position; for the same strain comes upon the edge, whether it be up or down.

But if it resist more to tension than compression it would be stronger *when resting on its edge*, and *vice versa*. These conclusions are fully sustained by experiment. Mr. Couch made some experiments on triangular (Canadian) oak beams, fixed at one end and loaded at the other. The mean of four experiments gave,

with the angle upward, . . .	315 lbs.
" downward, . . .	348 "

(See Barlow's Strength of Materials, p. 118.)

2. Suppose the beam is made of cast iron.

Cast iron will resist about 6 times as much to compression as to tension (see Mahan's Civil Engineering, p. 82). Hence, if we suppose the yielding to be at the angle, the beam will be six times as strong when the angle is upward as when it is downward. I know of no experiments on triangular cast iron beams, but Barlow has made experiments which confirm us in our conclusion (see his Strength of Materials, p. 337; also, Mahan, p. 88). If the beam is fixed at one extremity instead of being supported, then it will be stronger with the angle downward. In a similar manner we might determine the relative strength of a beam in the two positions if made of any other material.

I now propose *to find the strongest trapezoidal beam which can be cut from a given triangular one.*

To investigate this case, we will resort to the fundamental expression for the resistance of beams subjected to a transverse strain.

Let R = the ultimate resistance of a unit of section to compression or extension.

$d_{,}$ = distance of the farthest fibre from the neutral surface.

I = moment of inertia of the section about an axis through its centre of gravity and parallel to the base.

We the have for the moment of resistance

$$\frac{R I}{d_{,}}$$

[See Mosley's Mechanics and Engineering Eq., (637).]

Let A B C be the given triangle.

A B E D the required trapezoid.

Let b=A B. v=D E.

a=C G=longest altitude of A B C. w=C F.

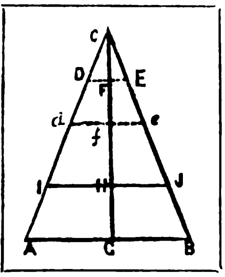
H=centre of gravity of the trapezoid A B E D.

$d_{,}$=F H. (2) z=C H=$d_{,}+w$.

I J is the neutral axis of the trapezoid.

To find C H, we have, from the equatiou of moments, origin at C,

$$\tfrac{1}{2}ab\,\tfrac{2}{3}a=\tfrac{1}{2}vw\,\tfrac{2}{3}w+\frac{b+v}{2}\,(a-w)\,z.$$



$$(3) \qquad \therefore \qquad z=\tfrac{2}{3}\,\frac{a^2b-vw^2}{(b+v)\,(a-w)}.$$

From the similarity of triangles we have

$$(4) \qquad v:w::b:a \qquad \therefore \qquad w=\frac{a}{b}\,v.$$

From (2) and (3) we have $d_{,}=z-w=\tfrac{2}{3}\,\dfrac{a^2b-vw^2}{(b+v)\,(a-w)}w$;

by substituting w from (4) we have

$$(5) \qquad d_{,}=\tfrac{1}{3}\,\frac{a}{b}\;\frac{2b^2-bv-v^2}{b+v}.$$

The moment of inertia about I J as an axis is equal to the moment of inertia about D E *minus* the area A B E D × $\overline{\text{F H}}^2$.

Let F$f=x$. $de=y$.

Then from the similar triangles C D E and $c\,d\,e$ we have

$$y:b::x+w \text{ or } x+\frac{a}{b}\,v:a.$$

$$\therefore \quad y=\frac{bx+av}{a}.$$

Hence, the moment of inertia about D E as an axis is

$$\int_0^{x=a-w}x^2y\,dx=\int_0^{\frac{a}{b}(b-v)}\frac{x^2}{a}(bx+av)\,dx=\frac{b}{a}\left[\frac{x^4}{4}\right]_0^{\frac{a}{b}(b-v)}+\left[\frac{v}{3}x^3\right]_0^{\frac{a}{b}(b-v)}$$

$$(6) \qquad = \frac{a^3}{12\,b^3}(3\,b^4 - 8\,b^3 v + 6\,b^2 v^2 - v^4).$$

Area of the trapezoid is

$$\frac{b+w}{2}(a-v) = \frac{a}{2\,b}(b^2 - w^2),$$

which multiplied by F H$^2 = d_{\prime}^2$ gives

$$(7) \qquad \frac{1}{36}\,\frac{a^3}{b^3}(b^2 - v^2)\left(\frac{2\,b^2 - b\,v - v^2}{b+v}\right)^2,$$

which subtracted from (6) gives the moment of inertia I J; which by reduction will become

$$(8)\quad I = \frac{1}{36}\,\frac{a^3}{b^3}\left[\frac{b^5 + b^4 v - 8\,b^3 v^2 + 8\,b^2 v_3 - b\,v^4 -}{b+v}\right.$$

If $v = 0$ this becomes $= \frac{1}{36}\,a^3 b$, which is the mor inertia of a triangle about an axis passing through its of gravity and parallel to its base.

By substituting (5) and (8) in (1) we have

$$(9)\quad R\frac{I}{d} = \frac{1}{12}\,R\,\frac{a^3}{b^3}\left[\frac{b^5 + b^4 v - 8\,b^3 v^2 + 8\,b^2 v^3 - b\,v}{2\,b^2 - b\,v - v^2}\right.$$

which is to be a maximum;

∴ we have

$$(10)\quad \frac{du}{dv} = 0 = v^6 + 2\,b v^5 - 5\,b^2 v^4 - 8\,b^3 v^3 + 19\,b^4 v^2 - 10\,{}^{5}$$

By discussing this equation we find that it has three each equal b, which gives a minimum. Divide Eq. (1 $(v-b)^3$, and we have

$$(11) \qquad v^3 + 5\,b\,v^2 + 7\,b^2 v - b^3 = 0$$

$$(12) \qquad \text{make} \quad v = \frac{z - 5\,b}{3} \text{ and 11 becomes}$$

$$z^3 - 12\,b^2 z - 92\,b^3 = 0,$$

which solved by Cardan's formula gives

$z = 5{\cdot}39118\,b$, and this in (12) gives

(13) $v = 0{\cdot}13093\,b$, and this in (4) gives

(14) $w = 0{\cdot}13093\,a$.

By substituting v, Eq. (13), in (9) it becomes

$$(15) \qquad R\frac{I}{d} = 0{\cdot}545625\,\frac{R\,a^2 b}{12}.$$

Making $v = 0$ in (9), we have the moment of the full triangular

$$(16) \qquad \text{section} \qquad = 0{\cdot}5\frac{\text{R}a^2b}{12}.$$

Dividing Eq. (15) by (16) gives 1·09125.

Hence, *if the angle of the prism be taken off to* ·13 *of its depth, the prism will be* 1·09125 *times as strong, which is a gain of over* 9 *per cent.*

Haupt, in his valuable work on Bridge construction, p. 51, says:

"It is found that the prism becomes one-thirty-seventh part stronger when the angle is taken off to one-tenth of the depth."

Making $v = \frac{1}{10}b$ in Eq. (9) and we have

$$(17) \qquad \text{R}\frac{\text{I}}{d_1} = 0{\cdot}54385\frac{\text{R}a^2b}{12},$$

which is $0{\cdot}04385\frac{\text{R}a^2b}{12}$ stronger than the full section. Dividing this by (16) we find that it is 0·0877, or more than one-twelfth part stronger.

Barlow, in his Strength of materials, p. 116, says "that it is the commonly received notion, that if the vertex, or upper edge of a triangular prismatic beam, be cut off to one-third the depth, the piece will be stronger than before."

To compare this "received notion" with theory, make $v = \frac{1}{3}b$ in (9), and we have

$$(18) \qquad 0{\cdot}465608\frac{\text{R}a^2b}{12},$$

which being divided by (16) gives 0·93101, or according to theory *this trapezoidal beam should be only ninety-three-hundredths as strong as the triangular one from which it is cut.*

This conclusion is sustained to a remarkable degree of exactness by the experiments of Mr. Couch as given by Barlow, p. 118.

The mean of seven experiments made by Mr. Couch on the strength of triangular oak beams with the angle upward, is 306 lbs.

The mean of two on trapezoidal beams with the narrow side up, made from triangular prisms of the same size used in the preceding experiments by cutting off the angle to one-third the depth, is 284·5 lbs., which is only four-hundredths lb. less than ·93 of 306 lbs.

By comparing expressions (15), (16), (17), and (18), and calling the strength of the triangular beam unity, we have the following results:

Strength of the triangular beam, . . , ...	1.
Strength of the same beam if the edge be cut off to $\frac{1}{3}$ the depth, . .	0.93101
" " " " $\frac{1}{10}$ " . .	1.0677
" " " " so as to give a maximum.	
Strength, ...	1.0912

In order to explain this apparent paradox, we must remember that the condition is not that the triangular beam shall be fractured completely through, but that it shall not be fractured at all. Now the *greatest strain* comes upon the edge, but there is only one fibre there to resist it; but after a small portion of the edge is removed there are many fibres along the line D E at equal distances from the neutral surface, each of which will sustain the same part of the *greatest strain.*

If the triangular beam were loaded so as to just commence fracturing at the edge, we might increase the load 9 per cent. and increase the fracture to only thirteen-hundredths of its depth; but if the load be increased beyond this amount, it will break the beam completely in two.

Again, Haupt says (p. 51), "It is found that the strength of the triangular prism is to that of a rectangular prism having the same base and altitude, as 339 : 1000 or nearly as 1 : 3."

The moment of resistance of the triangular section is, Eq. (16),

$$\frac{1}{24} \mathrm{E}\, a^2 b.$$

The moment of resistance of a rectangular section is well known to be (found from (1)),

$$(19) \qquad \frac{1}{6} \mathrm{E}\, a^2 b.$$

Hence, theoretically, they are to each other as 1 : 4.

I will close this article by comparing the maximum trapezoidal beam with a rectangular one having the same base and altitude.

Let $d =$ altitude $= 0{\cdot}87\,a$, nearly;

$$\therefore \qquad a^2 = \frac{d^2}{\cdot 7569},$$

which substituted in (15) gives

$$0{\cdot}72\,\frac{\text{R}\,d^2\,b}{12}.$$

And (19) becomes $\frac{1}{6}\,\text{R}\,d^2\,b$.

Hence the resistance of the maximum trapezoidal beam is that of a rectangular one having the same base and altitude as $\frac{1}{12}$ of $0{\cdot}72 : \frac{1}{6}$, or as 36 : 100.

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PREFACE.

THE wants of civilization are constantly expanding, and to supply these, ingenuity is continually taxed to invent new systems and appliances. Particularly is this so in closely settled communities. The family actually furnishes itself with but a small part of its daily wants. By a division of labor, the few minister to the wants of the many. Our clothing, many of our daily supplies, our lights, even the water we use, are furnished systematically, better and cheaper than we can supply them ourselves. One thing more was needed, viz.: a system of heat distribution.

Mr. Birdsill Holly, through the agency of steam, is the first to solve this problem; and "THE HOLLY STEAM COMBINATION COMPANY, of Lockport, N. Y.," was formed to practically demonstrate the utility of his inventions.

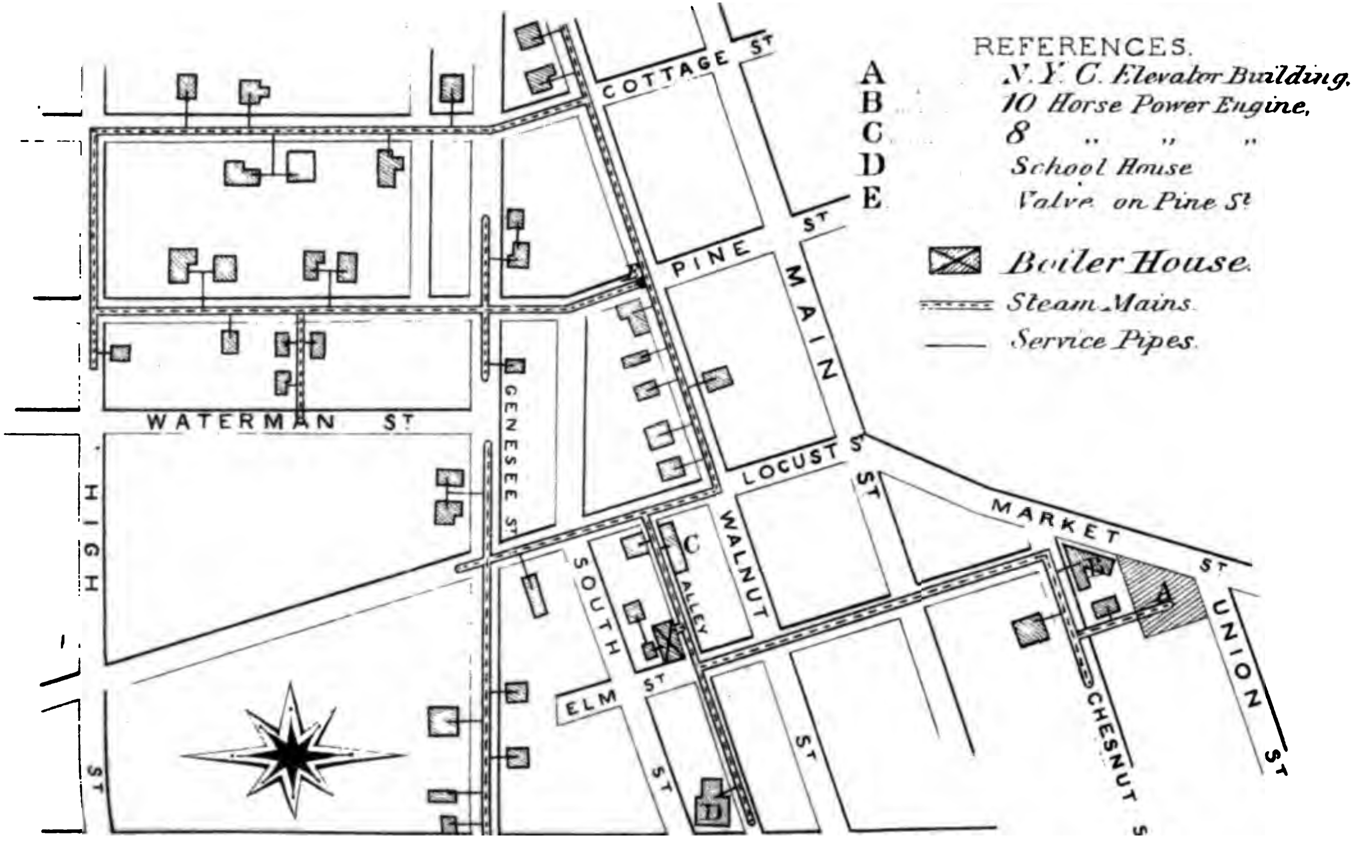
Assured of complete success, after a winter of actual operation, we greet a long-suffering public, and in the following pages, set forth somewhat in detail, the measure of our success, and the methods of accomplishment.

The Plates here exhibited are designed to give the reader a general idea of the uses of the special parts of the system, without the burden of a minute mechanical description, which is reserved for engineers and persons directly interested in putting in the work.

PLAN OF

LOCKPORT, N.Y.

Showing District now heated by "The Holly Steam Combination Co"



THE HOLLY SYSTEM

OF

STEAM HEATING

FOR CITIES AND VILLAGES.

WARMTH is the essential condition of life in the human body, and vitality ceases when warmth departs. Its proper distribution is necessary to our health and happiness. Climatic changes from day to day tend constantly to destroy the equilibrium of our comfort. Food supplies carbon, one of the elements of heat; clothing wards off the rude blast, and prevents too rapid radiation from our bodies. These are prime necessities, but they are not enough.

Through much of the year we still require artificial warmth in our homes. How to secure this warmth to a proper degree economically and to maintain pure the air that we breathe, has been the study of many minds and the subject of many inventions. The transition from the open fire-place of our fathers to modern appliances has been in the line of labor-saving and economy in fuel, but not in the direction of pure air and wholesome living. Stoves and furnaces, though serving a valuable purpose, are subject to grave objections. At best they are imperfect heaters. They pollute the air with dust. Deleterious gases escaping are stealthily commingled with the atmosphere which we breathe, and are the cause of not a few serious ailments.

STEAM HEATING

is doubtless the climax of all the adaptations thus far in supplying artificial heat. This agent, the world's mighty working power, which drags heavy trains across continents and drives the merchant ship across the ocean, can yet perform the more quiet but not less useful and effective service of warming the homes of millions who dwell in cities and villages.

To quite an extent steam is already used in heating buildings. But the boiler and fixtures for single dwellings are very expensive, as is also the maintenance. Some years since, Mr. Birdsill Holly, a celebrated engineer, and the inventor of the Holly Water Works system, etc., etc., conceived the idea that steam could be supplied from a central point, not only for power but to heat large districts of dwellings, stores, and other buildings in cities and villages, the same as gas and water have been for a long time. Subsequently he put his ideas into an experimentally practical shape, which soon satisfied him that the plan was entirely feasible if properly worked out.

In January, 1877, the Holly Steam Combination Company, of Lockport, N. Y., was formed under the statute, with necessary capital to test the plan on a large scale. Three miles of underground pipe were laid, but little of it larger than four inches diameter, and after a series of exact tests and detailed practical experiments, and after the experience of a variable and peculiarly trying winter, the system is pronounced by all to be a practical and perfect success.

We exhibit herewith a plan *(see plate page 4,)* of the district now being heated, with the position of the mains, buildings, etc. The company has through the winter been heating about forty large dwellings, scattered along the line, also a large school building, 105,000 cubic feet, and the largest hall in the city, besides furnishing steam to run two engines, one of them nearly half a mile distant from the boiler-house, and are supplying steam for a number of other purposes.

Houses a mile away are heated as readily as those near at hand. Three boilers are in position, two of them horizontal, 5 by 16 feet, and one upright. In the coldest weather two were fired slowly, but much of the time the steam has been furnished by a single boiler. The fire is, of course, kept up constantly. Two firemen do all the work, one for the day and one for the night. They can do the same work for three hundred or four hundred dwellings, when that number is attached along the line. Careful experiments demonstrate the fact, that with sufficient boiler capacity, and pipes of proper size, an area of more than four miles square in any city or village can be warmed from one set of boilers. The arrangement of boilers by this system is deserving of special attention. Our building is intended to contain six boilers. *(See plate No. 2.)* The street main will have two connections with this

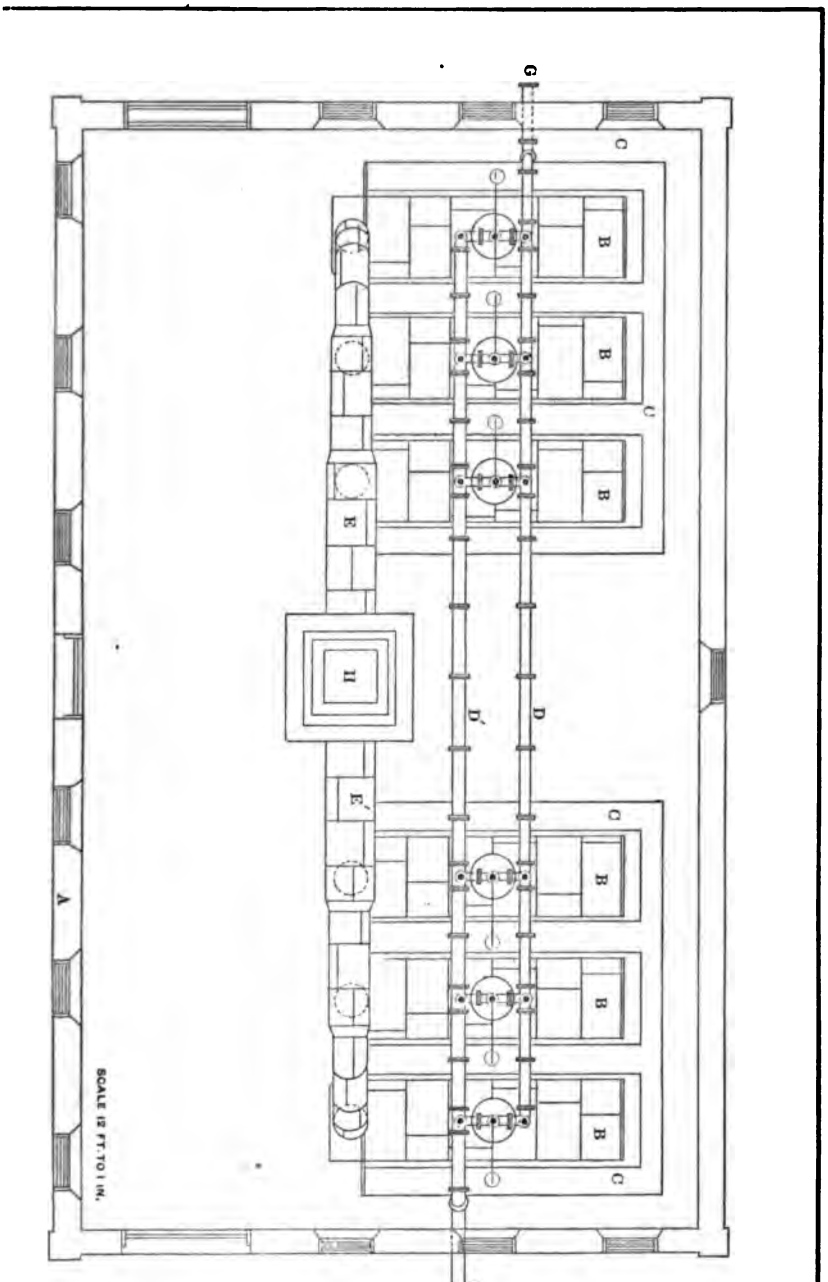


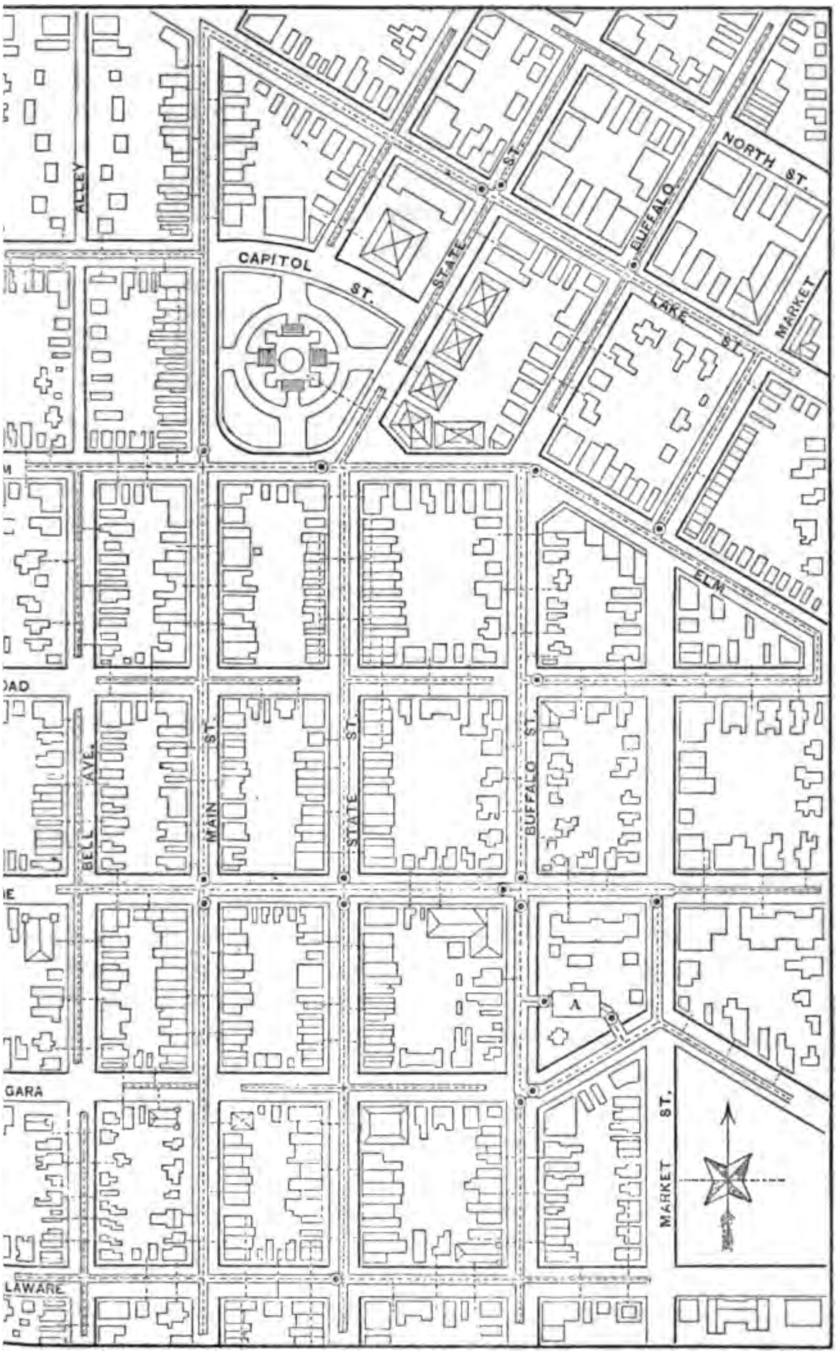
PLATE No. 2.

train, one at each corner of the building on the north side. A larger building for a larger system, will contain an increased number. If one boiler from any cause is disabled, it will not interfere with the operations of the others. In the coldest weather, if necessary, the whole number can be fired. As the weather moderates, a part can be dropped out of service, or they can be used alternately to facilitate occasional cleaning.

We present also a drawing, *(see plate No.* 3,*)* showing a section of district designed to be heated in an imaginary city, with streets, dwellings, stores, factories, etc. In the plan submitted are 200 stores with offices, 200 dwellings, 9 churches, and about 20 factories. Estimating the cubical contents of the stores as averaging 50,000 cubic feet, dwellings 10,000, churches 200,000, factories 100,000, we have

200 Stores........................	10,000,000	cubic feet.
200 Dwellings....................	2,000,000	"
9 Churches......................	1,800,000	"
20 Factories......................	2,000,000	"
Total........................	15,800,000	cubic feet.

This space is to be warmed by one battery of ten boilers, each 5 feet diameter by 16 feet long. The boiler-house is at *A*, intersection of Niagara and Buffalo streets. Two eight inch mains lead from the house, one into Niagara street, connecting with an eight inch street main. The other connects with the eight inch main in Buffalo street, the two intersecting the main in Pine street, which is also eight inches, thus forming a circuit of eight inch pipe around the block in which the boiler-house is located. The arrangement is such that it will be impossible for the district to be deprived of steam at any time, for in case of accident, any one of the mains can be closed without interfering with the general circuit. Suppose it necessary to close the main on Buffalo street, between Pine and Niagara, the steam will leave the opposite end of the building and through Market street to Pine, and through Buffalo to Delaware, it will connect with all parts of the district. The mains throughout the entire district are divided into sections, each of which is so controlled by the arrangement of valves, that it can be closed, or shut off, in case of necessity, without inconvenience to the other sections; but as this is of rare occurrence, the precaution is simply a safeguard. By these arrangements and connections, any part of the district



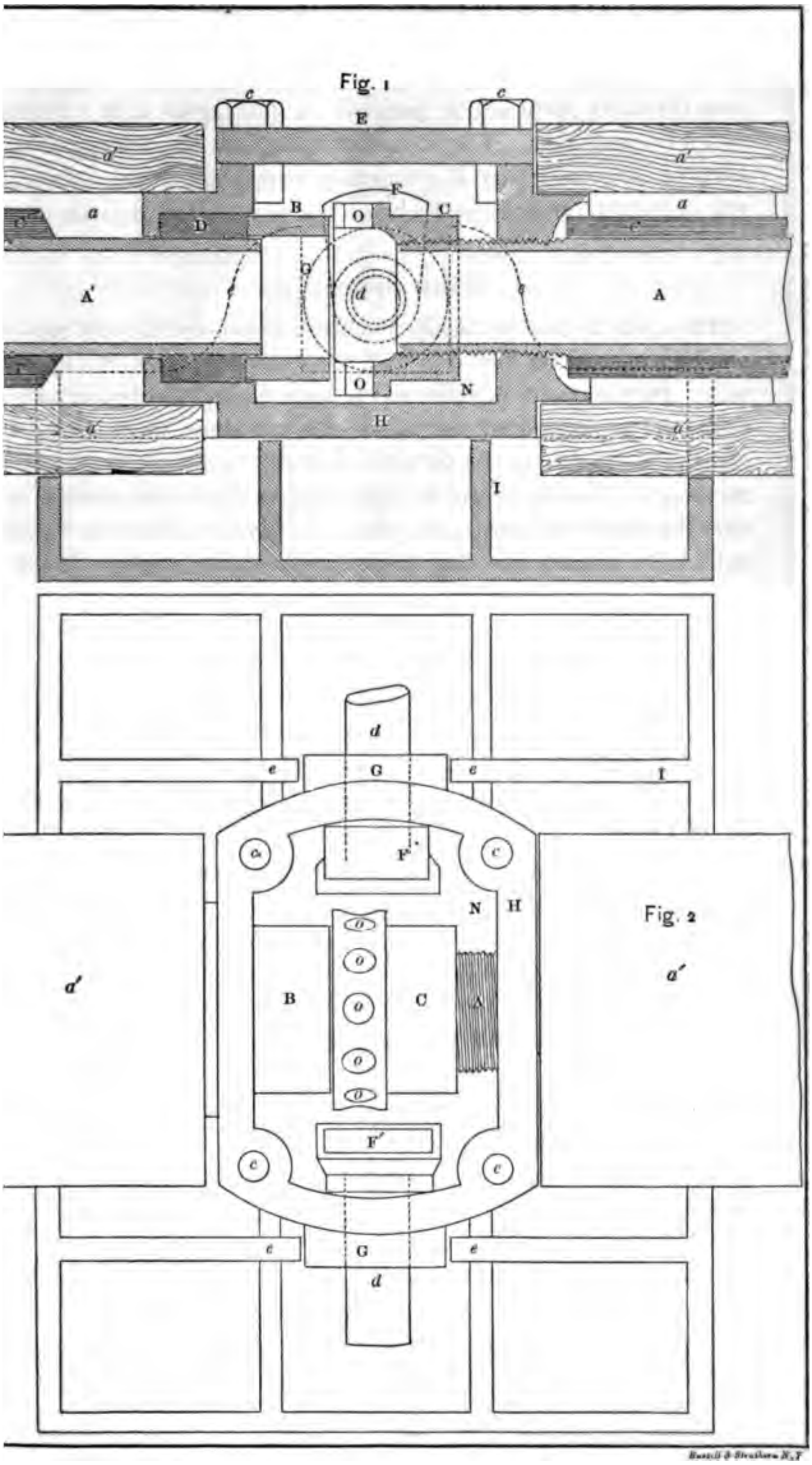
SCALE 500 FT. - ONE INCH

PLATE No. 3.

which may be for the time drawing a large amount of steam, may be reinforced from opposite directions, and thus the pressure be evenly maintained throughout the entire district. The pipes, as they radiate and approach the limits of the district, decrease in size from eight inches to one and one-half inches in diameter, to correspond with the amount of steam to be passed. It will be seen that much smaller and less expensive pipes are used than are necessary in the low-pressure system, which is used to advantage in single buildings, but could not be employed in an extended system of street mains. Under the low-pressure system in the pipes, the amount of steam which can be delivered is very limited. But by Mr. Holly's system of regulation, low-pressure, 4 lbs. or less, is secured in the building, while 60 lbs or more may be carried in the boilers and mains. It will readily be seen that with this amount of pressure, a small pipe will deliver an immense quantity of steam, while the conditions in the building are always uniform and safe. These mains are laid in ditches dug in the streets, three to four feet deep, so as to be above the gas and water pipes. The pipe is covered with non-conducting materials, and then inserted in logs of wood bored for the purpose. These are laid over tile to secure drainage. The drainage is also an improvement to the street after the ground becomes settled.

THE CONTRACTION AND EXPANSION

of the iron for conveying steam long distances, has been a real obstacle to successful operations. In this system, an expansion junction service box is placed at intervals of 100 to 200 feet in the line. *(See plate No. 4.)* This provides for the free longitudinal expansion and contraction of the mains, and from this box the service pipes are carried under ground to the basement of buildings to be heated. The service pipes having an adjustable hood inside the junction box, may be turned downward, thus taking up the water of condensation as fast as it accumulates, and carrying it forward to the regulator valve inside the cellar walls, as shown in plate No. 5. At this point, the water of condensation being at the degree of heat due to 50 lbs. pressure to the square inch,—is wire-drawn, and by this reduction of pressure, it is largely re-converted into steam, and is carried on to the radiators, where it is again condensed. By this device it will be seen that although 50 lbs. pressure is carried in the mains, it may be reduced to one or two lbs. in the building, and therefore in a house two or three miles distant



Russell & Struthers N.Y.

PLATE NO. 4.

from the boiler there will be precisely the same result as in a building only a few feet away. The consumer living near the boiler-house will have no advantage over the consumer living a mile away, since each will ordinarily carry the same house pressure—which is steam at the same temperature.

STEAM FIRE ENGINES.

These will be greatly simplified in construction, and the cost reduced one-half or more, as the boiler and furnace will be entirely dispensed with. On the streets of cities and villages having a reservoir system, steam will be taken from the main to the curbstone, where a pipe will come to the surface beside the street hydrant. *(See cut, last page, on the cover.)* The engine will be comparatively cheap and portable, and after the alarm, will arrive promptly on the ground without the frightful noise and confusion attending the ordinary steam fire-engine. It will at once take power from the steam pipe, and suction from the hydrant. The power will be always up, and by having the steam pipe impinge against the base of the hydrant, freezing will be prevented in the coldest weather. While it will not, perhaps, reduce the number of firemen, it will increase their efficiency and greatly diminish the cost and current expenses of the fire system. The effectiveness of steam itself as an element applied directly to the entinguishment of fires, is well known in the oil regions. In burning buildings the fire often rages under the floors between the joists, where it cannot be reached by water. Steam being lighter than air, when poured into such a building in sufficient quantity, rises and fills these spaces, thus preventing combustion. A two-inch pipe, at 60 pounds pressure, will deliver 5,000 cubic feet of steam per minute, which would make a body of steam two feet deep below the ceiling, in a room 25 by 100 feet.

ICE AND SNOW

can easily and cheaply be removed from streets and sidewalks, where in large cities it is frequently a serious obstacle to ordinary locomotion and traffic.

A receptacle one by six feet, near the curbstone, with a steam coil at the bottom, will melt the snow as fast as delivered therein, and the water will be conveyed to the adjacent sewer.

Experiments show that the cost in fuel of melting a ton of snow in this manner will not exceed five cents.

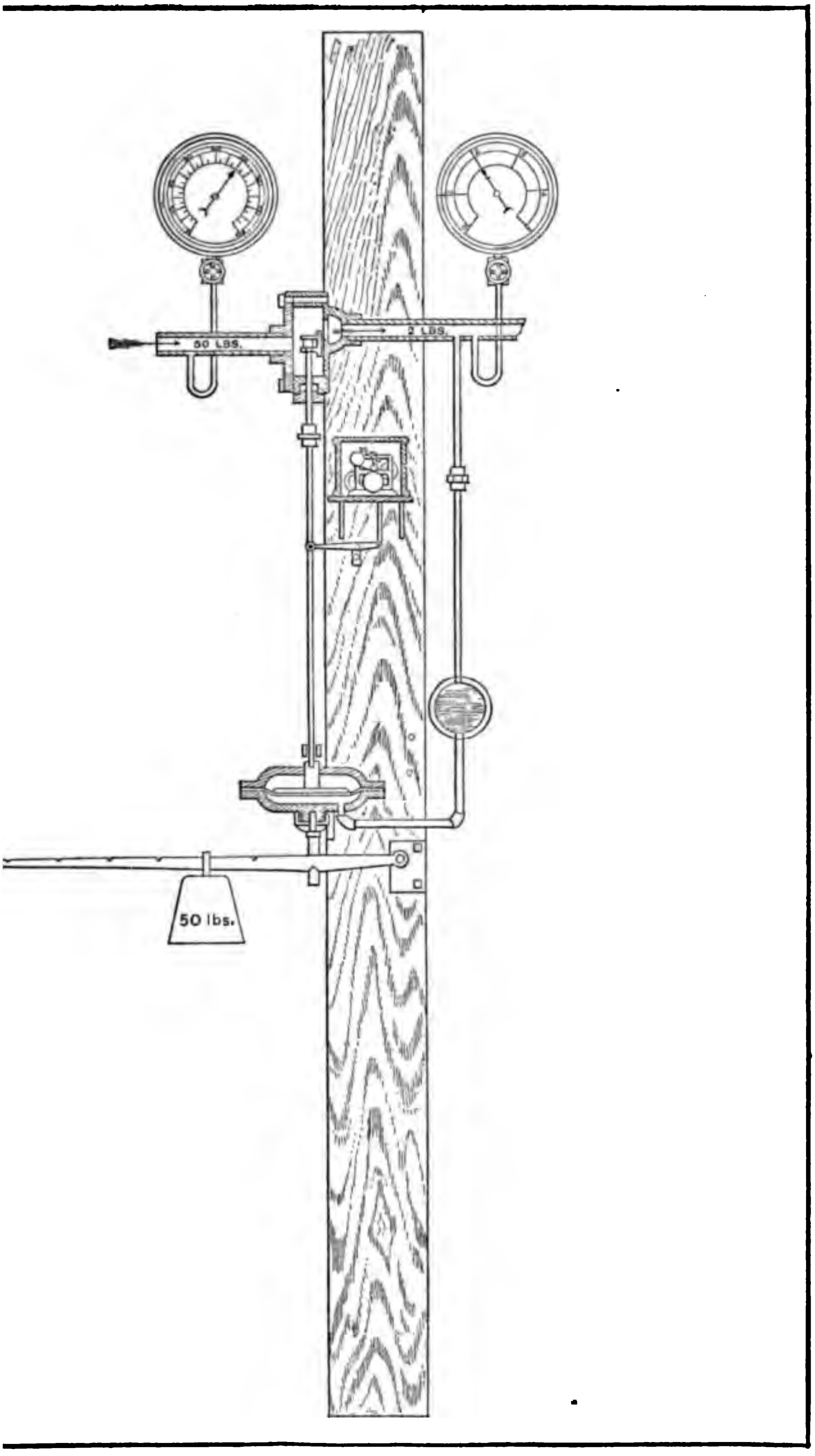


Plate No. 5.

GREENHOUSES AND CONSERVATORIES.

In addition to the services mentioned above, with steam under this system, we also heat greenhouses and conservatories, either by the steam direct, or by the circulation of the water of condensation. By an ingenious contrivance of Mr. Holly, water can also be carried to all the rooms in a dwelling, either by atmospheric pressure, or by the application of the direct force of steam for that purpose, *(see plate No.* 7,*)* without pump or engine.

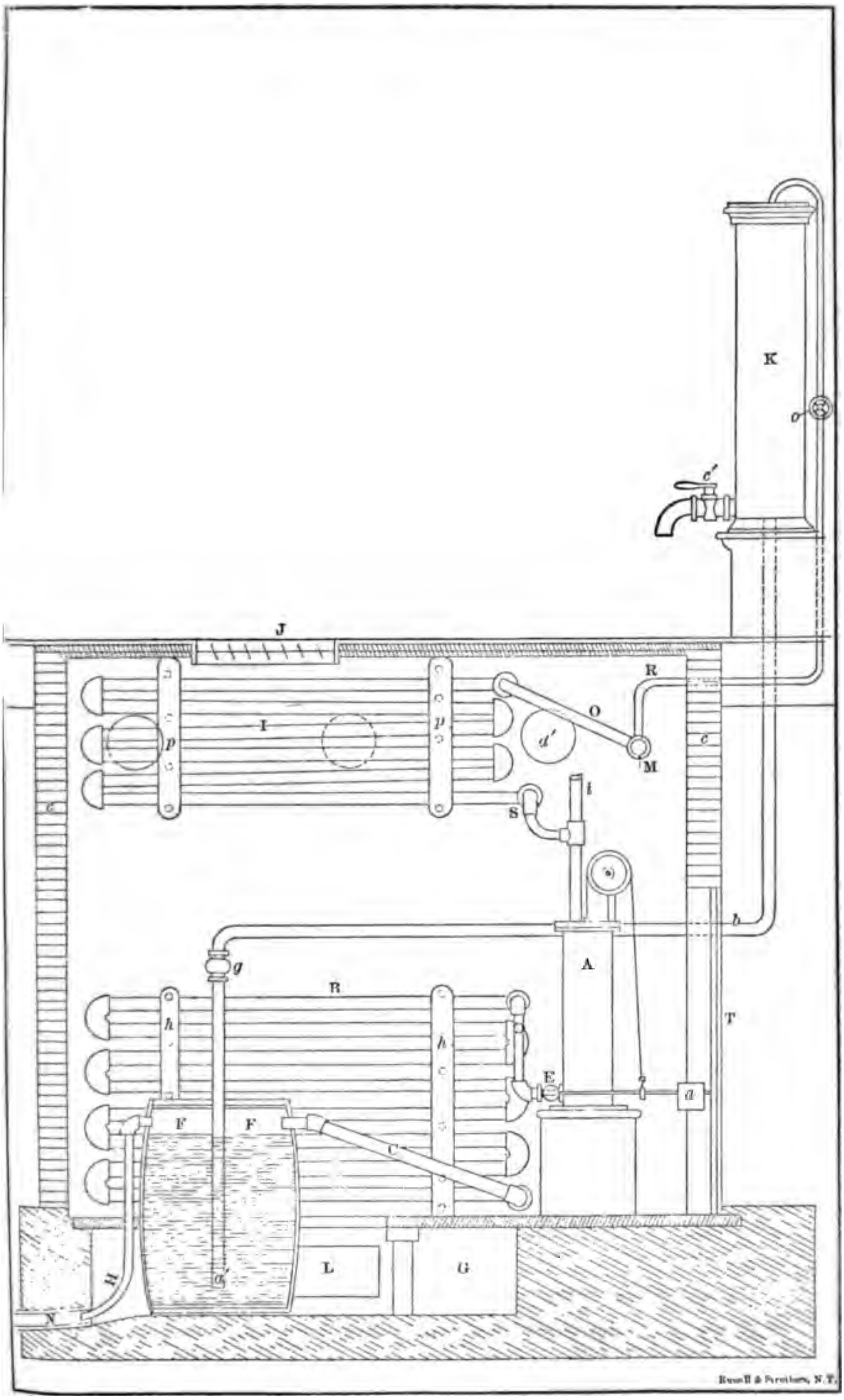
The accumulator shown at *K*, is a thin cast-iron pipe 8 or 10 inches in diameter, capped at both ends, placed upright in kitchen, bath-room or where wanted—with a half inch pipe leading from the tank in the cellar, into the bottom of the Accumulator, provided with a check valve at the tank-end. Also a three-eighths inch steam pipe leading from the cellar into the top of the Accumulator, shown at *R*, the water for use being drawn from the bottom, through valve *c*.

OPERATION.

On opening valves *o* and *c*, the steam will enter at the top and drive the air out at *c*. Then close both valves, and the steam will condense and form a vacuum, when the space will be filled with water from the tank below. It is then ready for use. If a quantity of water is drawn by opening both valves, the space will soon be filled by closing both valves. If the water is to be stored in a

TANK IN THE ATTIC,

the three-eighths inch steam pipe described above should be attached above the regulating valve, where it will get the full pressure of the street mains. Then with a half inch pipe, with check valve leading from the bottom of the Accumulator to the tank in the attic, we have only to fill the Accumulator as before described, then open the steam valve *o*, which will produce a pressure of 30 to 50 pounds to the inch, on the water in the Accumulator, and elevate it to the tank above, even 60 or 80 feet high. The water in the tank can be kept hot if desired, by leaving valve *o* open after the water is out of the Accumulator, the steam passing through the water-pipe into that noiseless box before mentioned, which may be placed inside the tank.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Russell & Struthers, N. Y.

PLATE NO. 7.

Machinery for a great variety of light mechanical and manufacturing purposes, which exists in all cities, will be operated, and the exhaust steam used for heating in the same building.

We have thus detailed some of the uses to which steam is being applied, under this system. Steam heating is not new, as many large establishments have for years been warmed through a great length of pipe. But the supplying of steam *to the public*, *by measure*, *at a price*, and its delivery through mains and laterals of iron pipe laid in the public streets, is entirely novel. Others may have entertained the vague *idea* that districts of dwellings could be supplied with steam for heating and power, but they never yet have invented the instruments or appliances by which it could be done. Without certain vital parts and combinations, the system of Mr. Holly would be imaginary only. Through his skill and genius he has invented these indispensable links to a perfect working plan, and they are secured by letters patent. Without undertaking to detail or describe all of the various devices employed, we have briefly stated a few of the obstacles which are overcome by them.

The popular belief is that steam cannot be carried a long distance effectively on account of its rapid

CONDENSATION.

But accurate experiments through a mile and a third of continuous small pipe, properly protected, show that the per cent. of loss is very small, and that this is, in fact, no hindrance whatever. The following table shows the size of districts that may be economically heated through the different sizes of pipe under this system:

Size of Pipe in inches.	Capacity per 1600 feet in lbs. of coal per hour.	Distance in feet from boiler that steam can be economically furnished.
1½	66	1,000
3	400	3,000
6	2,400	9,000
12	14,400	18,000

Condensation in a six inch pipe is double that of a three inch pipe, but it will deliver six times as much steam.

STEAM TRAP.

The hot water, with a portion of steam from the radiators, passes to the trap in the basement, *(see plate No.* 8,*)* where it is separated, and

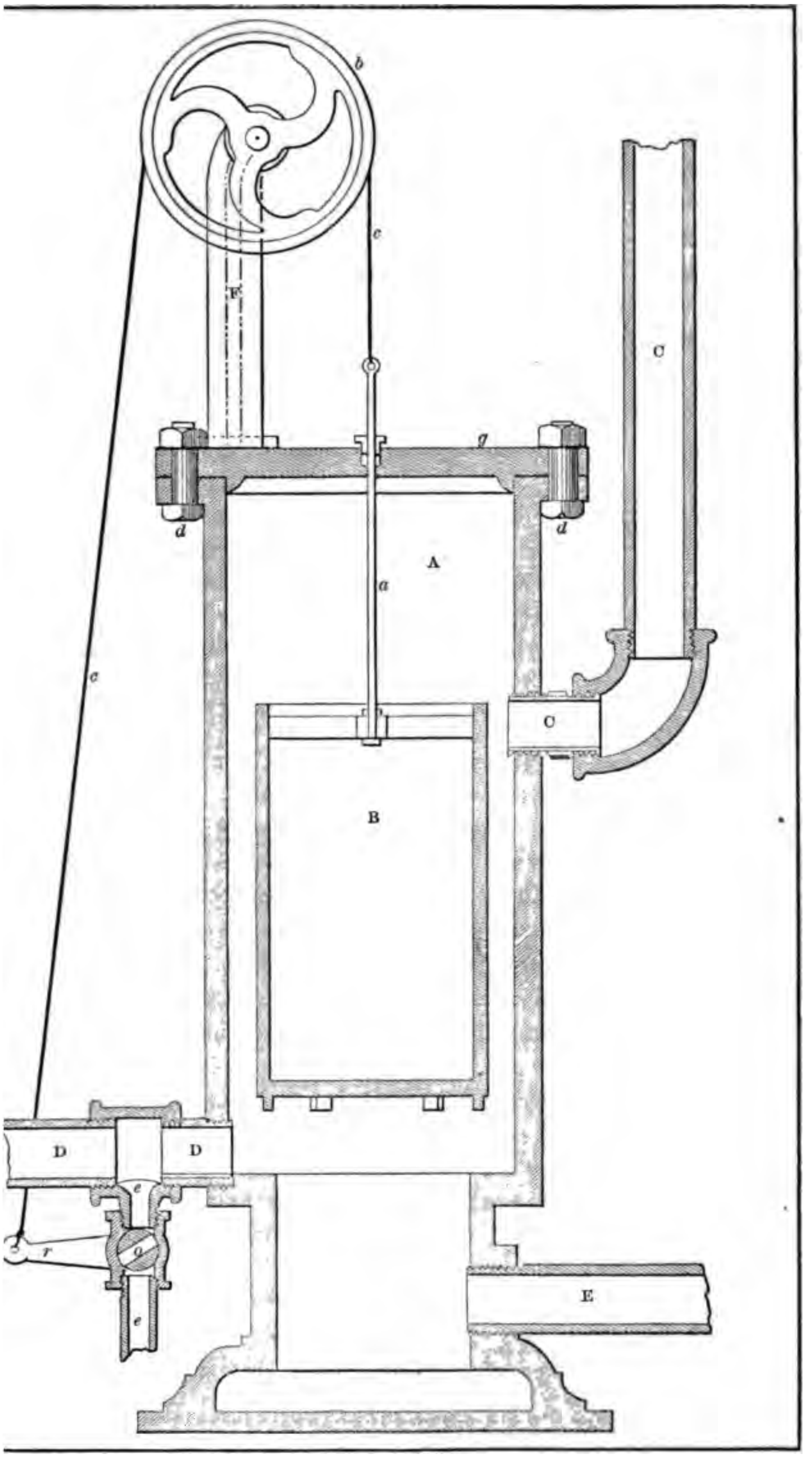


Plate No. 8.

is circulated through coils of pipe within a brick inclosure. Through this box, air is passed from the outside of the building, and through a register, usually in the floor of the hall above. This extracts all the heat from the water, and produces adequate ventilation, and a delightful summer-like atmosphere. The water from the coil is discharged into a tank, and the overflow goes to the sewer. The water thus stored is very desirable for all household purposes, it being chemically pure, and is raised to the Accumulator above, as heretofore described.

A STEAM METER

has been invented by Mr. Holly, *(see plate No. 9,)* which records accurately the amount of steam used by each consumer. The record is made by a pencil on a ribbon of paper which is moved by clock work. The pencil denotes the quantity of steam used, and the time of day at which each radiator in the house was put on or taken off. Thus each consumer pays for what he uses, and for no more. In this way, equitable dealing is maintained between the company and its consumers.

CONVENIENCE, NEATNESS, HEALTH.

The expense of gas is several times that of kerosene, yet it is extensively used in preference, because always at hand, safer and better. Since steam can be supplied in the same way, by simply opening a valve, and at no increase of expense, why should it not come into general use? There will be no storage of coal or removal of ashes. The dust which gives the careful housekeeper so much annoyance by settling upon carpets and furniture and the decorations of walls and ceilings, is banished, and much labor saved and damage prevented.

This dust, together with more or less gas escaping and being breathed by those who are necessarily confined much of the time within doors, is the cause of many throat difficulties and headaches, to which some persons are subject during the winter season. Steam heat, in connection with our indirect system of ventilation, proves in actual experience a perfect remedy for these difficulties in numerous cases.

Why do people so frequently take cold at home, with no special exposure, and why is the current and popular belief that "we take cold more readily in the house than in the open air," so often verified? Simply in consequence of vitiated or impure air, from want of ventilation, and the escape of deleterious gases, dust, and the smoke from

Fig. 1

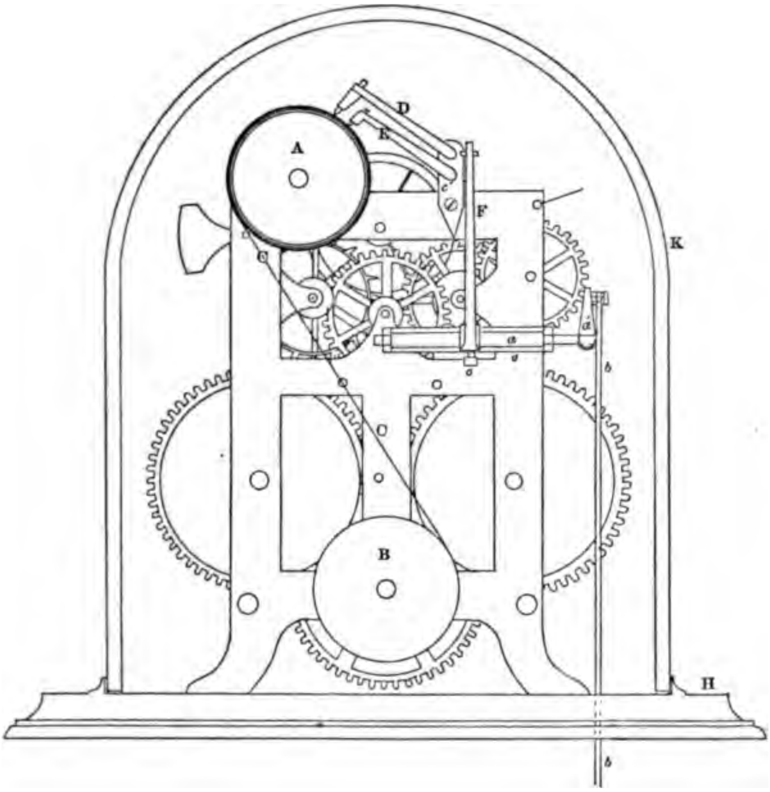


Fig. 2

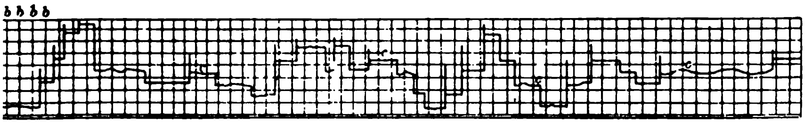


PLATE NO. 9.

stoves and furnaces; and also from falling and frequently changing temperature.

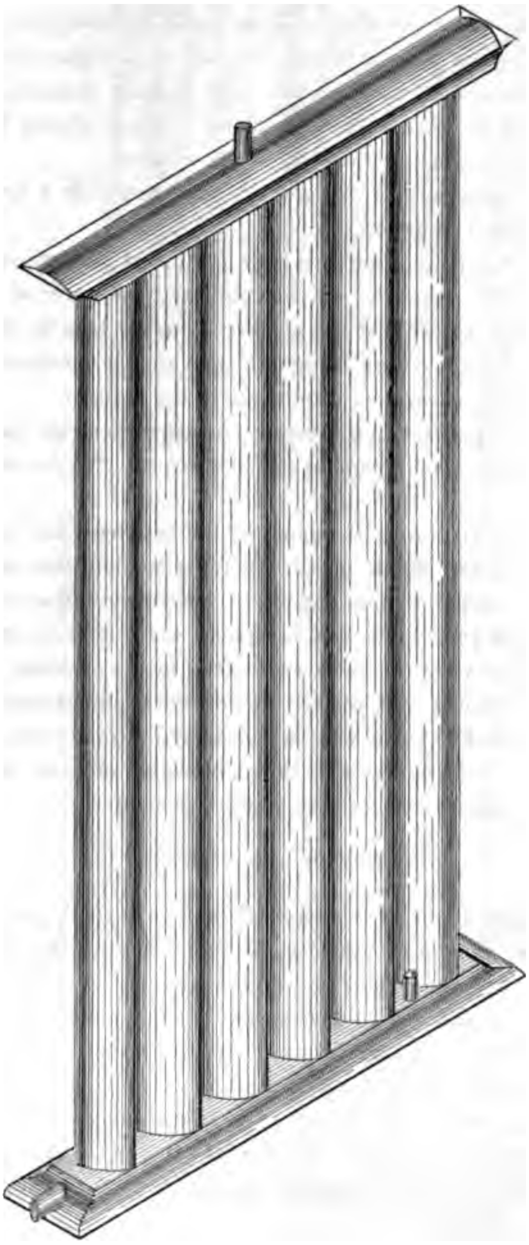
Uniformity of temperature, as well as a proper degree of heat and moisture, is essential to comfort and health, not only during the day, while the head and hands are at work, but as much during the hours of rest and sleep. It is a mistake that "a cold sleeping-room is better than a comfortably warm room." While thorough ventilation is necessary in a sleeping apartment, it is not true, as is often claimed, that "there should be no artificial heat." But on the contrary, it is one of the most important of all health questions to secure a uniform and properly warmed atmosphere to sleep in. When the mind and body are at work, the system is much better fortified against the effects of change of temperature, the inhalation of noxious gases, etc.; therefore we must see to it that our sleeping apartments, first of all, shall be supplied with pure, warm air. How to best accomplish this seems evident, since no other system of heating is absolutely free from dust, gas, and the sudden rising and falling of temperature.

RADIATORS.

This system admits of the use of all kinds of Radiators, both direct and indirect, and is a combination as already described, of the two methods of heating. We are using, with entire approval, the radiator made by the Walworth Manufacturing Company, of Boston. The size of radiator, of course, should be proportioned to the amount of space to be warmed, in the different rooms of the building, and to their exposure. As, when live steam is delivered to a building, no matter where made, perfect service is merely a question of fixtures.

ATMOSPHERIC RADIATORS.

Mr. Holly's new radiator *(see plates* 10 *and* 11*)* is so named for the reason that the pressure is always the same as the pressure of the atmosphere. It is made of thin sheet copper, galvanized iron, or other durable sheet metals. Upright tubes, three or four inches in diameter, are connected with a horizontal cap and base of the same or a different material, with openings in the base to allow the air to pass freely in and out. Thus a little steam brought into the cap will occupy the upper portions of all the tubes, and the inlet valve will be set according to the amount of heat desired in the room. Steam being lighter than air can be made to occupy any part or the whole of the radiator, and in



Russell & Struthers N. Y.

PLATE NO. 10.

no case can there be more than atmospheric pressure. The adjustment of the inlet valve for any given amount of heat can be depended upon, inasmuch as the pressure of steam in the building is kept uniform by the regulator before described. Thus it will be seen that the temperature of the room may be raised one degree or eighty degrees, as required, and maintained until the inlet valve is again changed.

Advantages of the Atmospheric Radiator: *First*—It can be made and put up for about half the cost of other radiators.

Second—The same surface will give off more heat than a heavy cast iron or wrought iron radiator.

Third—A very small portion or a large portion of its surface may be made hot, while the remainder will be cold; and the water of condensation will give off all its heat and go directly to the tank in the cellar, at a low temperature. There being no valve or back pressure in the return pipe, no water can ever accumulate in the radiator.

There being no pressure in the outlet pipe after the steam has passed the valve, no water can escape to soil the carpet. No air valves are required.

Fourth—Condensation in the pipes in the basement and about the building is reduced to about one-third of the amount due to the old system, for the reason that a one-fourth inch steam pipe will supply radiators to warm 6000 cubic feet of space, while it requires a three-fourths inch pipe to warm 3000 cubic feet by the ordinary method. The return pipe being cold, there is no condensation, consequently no covering is required. As no trap is necessary in connection with this radiator, it will be very desirable in many places, such as shops and offices, and in houses where there is no basement.

ECONOMY OF THE SYSTEM.

The tests made during the winter establish this beyond question, viz: That the same amount of heat can be supplied at a good profit for what the coal and wood bills of consumers would be for stoves and furnaces, and the quality infinitely superior. And at the same time the loss on stoves, stove-pipes and furnaces by deterioration is saved. Any one, by a little reflection and examination in a general way, will understand the saving effected, inasmuch as it is well understood that, as a rule, the coal bill is about half of the total expense of an apparatus—estimating the ordinary depreciation and repairs upon fixtures, the cost

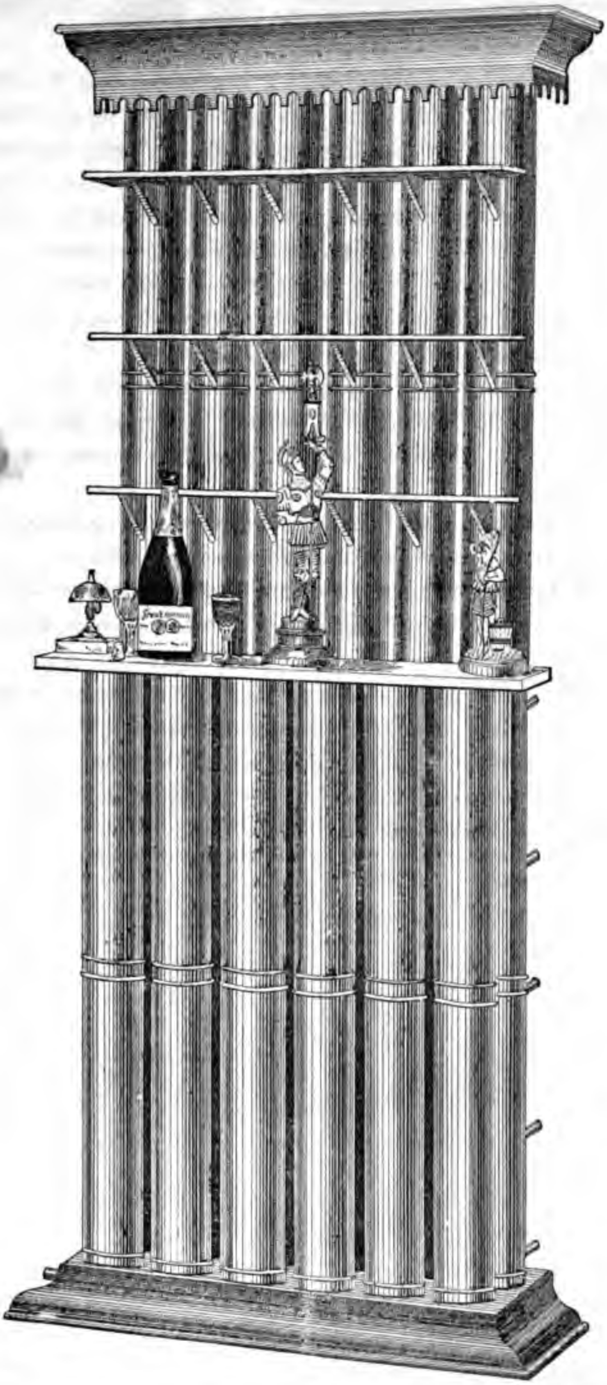


PLATE NO. 11.

of stoking, removing of ashes, etc. It is admitted that, by other systems, sixty per cent. of the heat goes up the smoke pipe. Under this system this waste is practically stopped, the loss being confined to a single stack at the boilers, which may serve to supply steam for several hundreds or thousands of buildings, while the care and labor of a single boiler establishment is substituted for as many separate establishments as may have connection with the works. By the use of cheap fuel, coal dust, or slack under the boilers, with a blower, it is at once seen that a further large saving may be effected.

It is expected that the Holly system of heating will be very extensively adopted within a short time, as stock companies are forming for the purpose in the Dominion of Canada, and in various cities in this and other States.

We are able to give other valuable information to those who would like to take an interest in this new and promising invention, and we invite all interested parties who can, to visit us during the present spring, and witness the work we are accomplishing. While the public have a general interest in the success of this new enterprise, it can be shown beyond a doubt that it also opens an extensive and remunerative field for the investment of some of the surplus capital of the country.

From the incredulous and criticising, we ask the closest examination, while we invite the co-operation of those who desire to become directly interested in a business point of view.

TESTIMONIALS.

LOCKPORT, N. Y., March 23, 1878.

To whom it may concern.

The Holly Steam Heating Company are now, and have been for months past, heating many private dwellings in this city, with, I believe, perfect satisfaction to their customers. They are also heating one of our largest public school buildings, and members of the Board of Education inform me that it is better heated than any other of the public buildings.

There are other features of this system besides the heating of buildings, to which it may be well to call your attention. At a very slight expense, comparatively, the fire hydrants of a city can be kept from freezing. The heavy steam engines now in use for fire purposes can be replaced by engines without boilers and furnaces, which may take steam from the street pipes at the hydrants, and being so much lighter, will certainly add to the usefulness of the fire department, and reduce materially the expense of its maintenance. Taken as a whole, I consider the invention one of the most valuable of the age, and rejoice that our city is provided with it.

H. D. McNEIL, *Mayor.*

LOCKPORT, N. Y., March 25, 1878.

To whom it may concern.

The system of conveying steam in pipes laid below the surface of the streets in this city, for heating and motive power, introduced by the "Holly Steam Combination Company" during the past year, has been under my observation while in construction and subsequent use, up to the present time.

So far no serious inconvenience to the public in the use of the streets has been occasioned while in process of construction. And since completion I am satisfied no damage or injury can result any more than would be the case with gas or water pipes.

As far as I am informed, all users of the steam are entirely satisfied, and their expectations more than realized, in the abundant supply of heat, with the perfect control of the same, as well as with the amount it costs.

S. F. GOODING, *City Surveyor.*

LOCKPORT, N. Y., March 25, 1878.

To whom it may concern.

I hereby state, for the encouragement of citizens, companies and corporations who contemplate adopting the heating system of the Holly Steam Combination Co., of Lockport, that the manner of laying street mains by this company does not materially interfere with the affairs of a public street, and when the work is completed the streets are in their former good condition.

JOHN W. BEEK, *Supt. of Streets.*

SURVEYOR'S OFFICE, LOCKPORT, N. Y., March 25, 1878.

I regard the manner of laying street mains and laterals adopted by the Holly Steam Combination Company, of Lockport, of advantage to the streets in which they are laid, for the reason of their drainage. All pipes are laid on a grade over drain tile, and with frequent connections with the sewer,—thus securing a dry condition of the earth at all times. JULIUS FREHSEE, *C. E. and Surveyor.*

LOCKPORT, N. Y., March 25, 1878.

To whom it may concern.

My dwelling house, No. 119 Genesee street, in this city, has been heated the past Winter by steam, furnished by the Holly Steam Combination Company, of Lockport, through their system of street mains. The heat thus furnished is very pleasant, and I consider this system a perfect success. A. HOLMES, *Ex-County Judge.*

LOCKPORT, N. Y., March 26, 1878.

To whom it may concern.

I hereby state that I have had power from the Holly Steam Company's street mains for running my engine, with which I run a 28 inch buzz saw, and an axe for working cord wood into stove wood, and at all times have ample power for the work.

DANIEL K. HUMPHREY, *Locust St. Wood Yard.*

LOCKPORT, N. Y., March 25, 1878.

To whom it may concern.

I take pleasure in stating that the Holly Steam Combination Co. has supplied steam for my 10-horse power engine, and for heating my entire building during the past winter. The power is prompt and efficient, which demonstrates beyond a question the success of the system. I prize the system very highly, on account of its safety from fire. My bakery and residence are nearly half a mile from the boiler-house. JOHN NOBLE, 69 Market Street.

LOCKPORT, N. Y., March 26, 1878.

To all parties interested.

Having used steam to heat my residence, corner of Walnut and Pine streets, during the past Winter, delivered by the Holly Steam Combination Company, through its system of street mains, I take pleasure in saying that the service has been performed in the most satisfactory manner.

The same Company, in addition to heating a large number of private residences, and running two engines, one of them half a mile away from the boiler-house, are also heating one of the largest public school buildings of the city.

In my official capacity, I have given the subject critical attention, and can but say that this building has been more perfectly warmed and ventilated than ever before.

On the score of comfort, health, convenience, and economy, I regard Mr. Holly's System, as in practice here, superior to all other plans or contrivances for heating residences and other buildings in cities and villages.

JAMES JACKSON, JR., *President Board of Education.*

LOCKPORT, N. Y., March 25, 1878.

To whom it may concern.

We, the undersigned, patrons of the Holly Steam Combination Co. of Lockport, ake pleasure in stating that our several residences have been thoroughly and pleasntly warmed during the past winter, by the system of under-ground steam mains nd laterals invented by Birdsill Holly, and that for reasons of cleanliness, uniformity f temperature, thereby securing health and comfort, and also for convenience and conomy ; we recommend this heating system to all who can avail themselves of s use.

O. C. WRIGHT, 26 Cottage St.
GEO. H. ELLIOTT, 182 Genesee Street.
JAMES JACKSON, JR., cor. Pine and Walnut Sts.
E. SIMMONS, 146 Walnut Street.
E. JAKEWAY, 34 Chestnut Street.
M. H. WEBBER, 141 Pine Street.
S. S. DICKERSON, 148 Cottage Street.
N. O. ALLEN, cor Cottage and Walnut Streets.
B. D. HALL, 188 Genesee Street.
W. E. McCOMB, 135 Pine Street.
D. J. CLAPSATTLE, 253 Genesee Street.
M. D. CLAPSATTLE, 243 Genesee Stret.
J. OSGOOD, 91 Cottage Street.
SAM'L ROGERS, 28 Walnut Street.
WM. H. HURD, 111 Cottage Street.
B. F. GASKILL, Genesee Street.
WM. J. BLACKLEY, 126 Walnut Street.
E. W. SCOTT, 50 Pine Street.
L. F. BOWEN, cor. Genesee and Cottage Sts.,
G. W. BOWEN, 185 Pine St.
A. K. POTTER, High St.
MRS. M. TUFT, 99 Cottage St.
LEONARD EVERETT, 121 Cottage St.
E. P. HOLLY, 8 Waterman St.
F. L. WRIGHT, Cor. Locust and Walnut Sts.
FRANK W. BALLOU, 177 Pine St.
WM. W. TREVOR, Walnut St.
BIRDSILL HOLLY, 3 Chestnut St.
MRS. C. HOLMES, 115 Genesee St.
MRS. A. M. GLASS, 268 Genesee St.
JACOB KIFF, 26 South St.
S. D. HOOPER, 129 Walnut St.
P. B. AIKIN, 91 Locust St.
S. R. DANIELS, N. Y. C. Elevator Building.
D. F. BISHOP, 252 Genesee St.

The foregoing brief testimonials have been kindly furnished us b persons using steam supplied through our street mains, and we woul refer to them with becoming pride as among our most honored citizens who had the faith and the enterprise last September and October t risk the requisite amount of money in placing steam fixtures in thei residences, and perhaps more than this, their reputation for sagacity, t assist us in proving by demonstration the grand scheme of our heatin system.

We thank them for these expressions of confidence and regard, believing that they are also thankful for the first luxury of this new system of heat.

We are particularly gratified that *every one* of our consumers ha been pleased to place himself on record here, and we most respectfull refer interested people to any one of the above named persons.

Respectfully,

D. F. Bishop, *President.*

REPORT

General Library, University, Mich.

ON THE

METHODS OF SURVEYING THE PUBLIC DOMAIN,

TO THE

SECRETARY OF THE INTERIOR,

AT THE

REQUEST OF THE NATIONAL ACADEMY OF SCIENCES.

By J. W. POWELL,
1878.

WASHINGTON.
GOVERNMENT PRINTING OFFICE
1878.

REPORT

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S. G[illegible] [illegible]
[illegible]

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1878.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1878.

REPORT

ON THE

METHODS OF SURVEYING THE PUBLIC DOMAIN.

DEPARTMENT OF THE INTERIOR,
U. S. GEOGRAPHICAL AND GEOLOGICAL SURVEY
OF THE ROCKY MOUNTAIN REGION,
[J. W. POWELL, IN CHARGE,]
Washington, D. C., November 1, 1878.

SIR: I have the honor to acknowledge the receipt of your communication of October 3, as follows:

"DEPARTMENT OF THE INTERIOR,
"*Washington, October 3, 1878.*

"Maj. J. W. POWELL,
"*Geologist in charge of the U. S. Geographical*
"*and Geological Survey of the Rocky Mountain Region:*

"SIR: I transmit herewith a copy of a letter from Prof. O. C. Marsh, acting president of the National Academy of Sciences, relative to that provision of the act making appropriation for sundry civil expenses of the government for the year ending June 30, 1879, which requires the academy to take into consideration certain matters relating to the surveys of a scientific character under the War or the Interior Department, and the surveys of the Land Office.

"I will thank you to furnish to this department a report upon the subject of said letter, giving such information as you may think will be of value to the committee of the academy.

"Very respectfully,

"C. SCHURZ,
"*Secretary.*"

And also the letter from Prof. O. C. Marsh, transmitted with the above, as follows:

"YALE COLLEGE, NEW HAVEN, CONN.,
"*September 28, 1878.*

"To the Hon. SECRETARY OF THE INTERIOR:

"SIR: Referring to 'An act making appropriation for sundry civil expenses,' &c. (H. R. 5130), Forty-fifth Congress, second session, relative to the consideration by the National Academy of Sciences, of 'all surveys of a scientific character under the War or Interior Department and the surveys of the Land Office,' I have the honor to say that a committee of the academy has been appointed and is now ready to consider the subject.

"I respectfully ask, therefore, that a communication may be addressed to me from your office conveying any information in regard to the plans and wishes of your department as to the above surveys you may think proper to lay before the academy.

"The next meeting of the academy will begin November 5, 1878, and an early reply, therefore, is desirable.

"Very respectfully, your obedient servant,

"O. C. MARSH,
"*Acting President of the National Academy of Sciences.*"

The letter was forwarded from my office and reached me in Utah, where I was engaged in field work, on the 14th of October. I immediately returned to Washington for the purpose of making reply.

The clause of the appropriation bill, referred to in the letter of Professor Marsh, is as follows:

"And the National Academy of Sciences is hereby required, at their next meeting, to take into consideration the methods and expenses of conducting all surveys of a scientific character under the War or Interior Department, and the surveys of the Land Office, and to report to Congress, as soon thereafter as may be practicable, a plan for surveying and mapping the Territories of the United States on such general system as will, in their judgment, secure the best results at the least possible cost, and also to recommend to Congress a suitable plan for the publication and distribution of the reports, maps, and documents, and other results of said surveys."

In reply to the above request, I beg leave to make the following statement:

The methods of conducting the surveys carried on under my direction, and the expense thereof, are set forth in the accompanying documents, marked A and B, as succinctly as I am able to present them. I beg leave, therefore, to refer the committee to the same, as my answer to the first part of the inquiry. Should the committee, however, desire a more elaborate and detailed reply, I shall be pleased to furnish it; or should it be deemed wise to ask specific questions relating to any portion of the work under my direction, I shall consider it an honor to reply as thoroughly and explicitly as I am able. I should consider it a privilege to explain to the committee, with the fullest detail, the methods of research pursued in my work, and should be pleased to lay before its members for examination the system employed in the geographical work, with instruments, systematic records, field sketches, &c., embracing the methods of measuring base lines, extending the triangulation therefrom, determination of altitudes, sketching the topography, construction of charts, &c., and the geological methods of research, embracing the succession and geographical distribution of the sedimentary groups, the character and distribution of the crystalline schists, the characteristics, classification, and distribution of the extravasated rocks, the methods of research and representation employed in the study of structural geology, &c.; and also the researches in North American ethnology, embracing linguistics, sociology, mythology, arts, &c., together with the geographical distribution of the tribes; and, finally, the limited studies made in natural history. The greater part of the work is yet unpublished, and for a proper understanding of what has been done it would be necessary to thoroughly examine the materials in my office.

In relaton to the next part of the inquiry, *i. e.*, as to "a plan for surveying and mapping the Territories of the United States on such general system as will * * * secure the best results at the least possible cost," I beg to submit the following suggestions:

For the past ten or twelve years different parties have been engaged in this work, pursuing diverse methods and producing diverse results. Four distinct autonomous geographical and geological surveys have been carried on simultaneously. In my answer to the resolution of inquiry from the House of Representatives, made on motion of the Hon. J. D. C. Atkins, chairman of the Committee on Appropriations, relating to the same subject, I made certain statements in my final remarks to which I beg to call attention. (*Vide* accompanying document marked B, being House of Representatives Ex. Doc., 80, Forty-fifth Congress, second session.)

The closing paragraph is as follows:

"In view of all these facts, it is manifest that the work should be unified and a common system adopted. This may be accomplished either by act of Congress, by executive direction, or by placing the work under one management."

I am still of the opinion that the unification which I advocated at that time would be wise; and desire to present additional reasons for the opinion then expressed.

I. The geographical work should be based on a transcontinental triangulation on a comprehensive plan, and carried on with proper refinement. With the work divided as it has been for the past ten years this is practically impossible. No one organization with its small appropriation can make the necessary outlay of money for the work without swallowing up the whole or greater part of its funds, and thus it would be prevented from doing other work. All of the scientific surveys which have been carried on for the past ten years are practically "in the air," because this fundamental condition of accuracy has been neglected.

II. For the hypsometric work transcontinental lines of levels should be established to which all the base stations in the field should be related by connecting lines. With the multiplicity of surveys and the small appropriations for each, it is impossible to have this work done, as it is impossible to have the transcontinental triangulation made.

III. All that portion of hypsometric work which is done by means of the barometer is to a greater or less extent inaccurate, from the fact that the barometric constants for North America have not been properly determined. The tables now in use are based on observations made at Saint Bernard and Geneva under climate conditions widely differing from those that obtain in this country. (*Vide* Williamson "On the Use of the Barometer," p. 220, *et seq.*: Pettie and Whitney, "Contributions to Barometric Hypsometry," in Report of the Geological Survey of California, and Lieut. Wm. L. Marshall, "Meteorology and Hypsometry," Appendix G 1, p. 370 of Report of the Chief of Engineers, 1876–'77, vol. II, part 3, and "Results in Barometric Hypsometry," p. 515 of Report of the United States Geographical and Geological Surveys West of the 100th Meridian, vol. II. A large amount of material on this subject has been collected by the survey under the direction of the writer, but remains unpublished.)

Series of observations must be made at suitable longitudes, latitudes, and altitudes within the territory to be surveyed, and from the data thus collected the tables must be prepared. As each survey is financially weak, and has but an uncertain tenure of existence, it is practically impossible to have these observations made.

The economic importance of hypsometric work is very great because of its relation to the agricultural industries of the country. In more than four-tenths of the United States agriculture is dependent upon irrigation, and in all of this region the hypsometric relations or relative levels of the land to adjacent streams by which they are to be fertilized must be determined. In all that vast area not a single farm can be cultivated or a site for an agricultural field selected without first determining by leveling the practicability of reaching it with water. While the government will not be expected to run lines of levels for individual farmers, yet in the selection of lands to be surveyed and sold these facts cannot be neglected.

The hypsometric methods now in use by the several surveys are entirely inadequate to meet these practical demands.

IV. The area to be mapped is very great. The expense of cartography is an important part of the total expense of the work. Each party being desirous of exhibiting the greatest results for the appropriations made, has endeavored to curtail the expense of cartography as far as possible. For this reason the maps have been reproduced by cheap methods to serve temporary purposes, and the future needs of the country have been ignored. To some extent, especially by Clarence King and by myself, the subject of cartography has been investigated and experiments made for the purpose of determining methods best adapted to the wants of the country, considering the magnitude of the work and the facts to be represented. But because each survey has been financially weak these experiments have not been carried to the extent which the importance of the subject demands, and we are thus adopting cartographic methods imperfect and ephemeral.

A system of cartography should be used that will best represent the characteristics of the topography and convey the greatest amount of practical information, limited only by considerations of cost. The maps thus constructed should be placed upon materials that are enduring, as all the natural topographic features are themselves enduring, so that thereafter the plates could be used by the government to meet all wants that may arise from time to time.

Finally the prosecution of the work by a number of autonomous organizations is illogical, unscientific, and in violation of the fundamental law of political economy, namely, the law of the division of labor. The work should be unified or integrated by placing it under one general management, and the division of labor should have a scientific basis; that is, it should be differentiated so that there shall be a division for geographical work embracing all methods of mensuration in latitudes, longitudes and altitudes, absolute and relative; and the representation of the results in appropriate charts. There should be a department of geology embracing all purely scientific subjects relating to geological structure and distribution, and practical subjects relating to mining and agricultural industries. If ethnology, botany, and zoology are to be embraced in the general scientific survey, each subject should have but a single organization, with a single head subordinated to the general plan. In such a way only can a proper integrated and differentiated organization be made. The present multiplication of organizations for all of these purposes is unscientific, excessively expensive, and altogether vicious; preventing comprehensive, thorough, and honest research, stimulating unhealthy rivalry, and leading to the production of sensational and briefly popular rather than solid and enduring results.

By the act of Congress the National Academy of Sciences is instructed to consider also the surveys of the public lands. These surveys have been carried on for nearly a century; primarily, for the purpose of *parceling* the lands in such a manner that titles to definite portions may be conveyed from the government to individuals; secondarily, that the value and characteristics of the lands may be determined. During the time in which these surveys have been in progress about 1,138,000 square miles have been surveyed, at a cost of a little more than $23,000,000, or at an average cost of a little more than $20 per square mile. In the prosecution of these surveys an attempt has been made to establish the boundaries of legal subdivisions, and maps have been constructed of every township surveyed, representing with greater or less accuracy the topographic features of the same, and each surveyor was required to note the character of the timber and certain facts relating to economic geology. For this work surveyors have been paid by contract for work done, instead of by salary for time employed. In pursuing this work the geography and geology of the country has been studied to some extent, but not with sufficient accuracy and thoroughness for scientific or general economic purposes. The only substantial result accruing therefrom has been the parceling of the lands by establishing boundaries, and even this has been imperfectly done by reason of certain faulty methods inherent in a system adopted nearly a century ago. Corners have been marked by planting wooden stakes where these were conveniently found, and in other regions, as the prairies, great plains, and naked valleys of the Rocky Mountain region, they have been marked by small heaps of earth, which could be easily raked together at the corners of subdivisions. But wooden stakes soon decay and heaps of earth are soon washed away by storms. In er districts the lines are further marked by blazing the trees adjacent thereto, and plats made by the surveyors were supposed to be additional means of identifying boundary-lines. To a large extent, however, these added securities have proved vailing. Marked trees are soon destroyed, and as no thorough topographic sys- was adopted the charts were practically valueless; hence the surveys of the pub- lands made for the purpose of parcelling the same have been of such a character at a heritage of litigation relating to boundary-lines has been bequeathed to pos- ity, ever increasing with the enhancing value of lands. For scientific purposes the ographic results exhibited on the charts made by the surveyors have been valueless r the following reasons:

Latitudes, longitudes, and altitudes have never been determined. The surveys have een proceeded from a number of initial points by north and south, and east and west ines. The geographic co-ordinates of these initial points were never determined, and no scientific checks were made in extending the lines therefrom.

The running of a straight line is an engineering feat of the greatest difficulty, and no proper precautions were taken to secure even approximately straight lines. In this manner, as the surveys proceeded from the several initial points, until they met, it was found that no two systems could be made to agree, and it became necessary to make connections by irregular fractional subdivisions, thus entailing on the land system a new set of difficulties. And, finally, in the topography and cartography no general system was adopted; the work has been given out by contract to deputy surveyors and even sublet; thus a large number of persons have been engaged annually in the work, each person adopting a system of his own, it being necessary only to comply with certain general regulations established by law.

Latitudes, longitudes, altitudes, and topographic positions were neither established absolutely nor relatively with accuracy, and the cartographic methods have been so diverse and imperfect that no general maps of value can be constructed from the vast number of township maps on file in the Land Office. For further information on this subject I refer to a little volume published by the Land Office, entitled "Instructions to Surveyors-General," and the "Report of the Hon. S. S. Burdett, Commissioner of the General Land Office, for the fiscal year ending June 30, 1875," and also to the "Report of the Hon. J. A. Williamson, Commissioner of the General Land Office, for the fiscal year ending June 30, 1877," copies of which are transmitted herewith, and in which the statements pertinent to the subjects in hand are marked.

The system of land surveys as originally adopted was, in many respects, wise, but it was never faithfully executed, from the fact that after its first inception it never had proper scientific supervision. From an early date, instead of having a single head, it has a multiplicity of heads; that is, there has been a number of surveyors-general (at present there are sixteen) working independently of each other, and practically autonomous. These surveyors-general do not directly conduct the surveys, but are law officers, intermediate between the General Land Office and the deputy surveyors who do the work, and hence are not chosen as experts, for their scientific qualifications, but are selected for their legal acquirements and administrative talents. For this reason it has happened that the system of surveys has not kept pace with modern science, and has scarcely been improved during the time (the greater part of a century) in which it has been in operation. It has failed to meet the economic and scientific wants of the country from the fact that it has lacked intelligent supervision on the one hand, and, on the other, that it has been carried out by a great number of deputy surveyors whose personal interests were opposed to accurate and scientific work, as they performed their labors under contract. A list of the initial points from which surveys have been made will be found in the accompanying document, marked "C."

There yet remains to be surveyed an area of about 1,704,000 square miles, exclusive of Alaska, and it is of paramount importance that the surveys of the public lands shall hereafter be conducted in such a manner as to avoid the evils above referred to.

There are on file in the General Land Office more than 35,000 manuscript maps, elaborately constructed on a scale of two miles to the inch, and representing the topographic features of more than 1,000,000 square miles of territory. Accompanying these maps is an equal number of manuscript reports relating to the geological and physical characteristics of the areas surveyed, the whole costing the government more than $23,000,000; and they are all of imperfect value in the parceling of the lands, of little or no value in the consideration of economic questions relating to the public lands, and absolutely valueless for scientific purposes.

These records of the Land Office furnish a gigantic illustration of the evils of badly-directed scientific work. A large corps of surveyors has been employed for nearly a century. Forests, prairies, plains, and mountains have been traversed in many directions; millions of miles have been run with compass and chain; chart after chart has been constructed with great labor; folio on folio has been placed among the national archives, containing facts incoherent and worthless; and the record has been made that here are trees, there swamps, and yonder glades; that the lands surveyed are level, hilly, or rolling; that sandstones are found here, limestones there, or granite elsewhere; and so the records of useless facts have been piled up from year to year until they are buried in their own mass. That all of this labor and expense has been lost to science, may well challenge the attention of the learned men of America, and when properly understood, they will not be slow in demanding a reform.

It is scarcely necessary to indicate to a scientific body a method by which these evils can be corrected in the future. There is one, and but one, adequate and inexpensive method. The initial points should be connected by a triangulation with a system of short base-lines accurately measured, the latter having their latitudes, longitudes, altitudes, and azimuths properly determined, and from the geodetic points established in this triangulation all the lines of the parceling surveys should be checked, and the datum points in the parceling surveys should be marked with imperishable monuments of stone or metal. By such a plan the boundary lines of parcels could be accurately and permanently fixed and easily identified. The corner-posts would not be immediately destroyed by natural agencies, and if lost by accident or removed by design, they could be easily and accurately replaced, and the whole basis of the system, in its geodetic points and triangles, would remain while hills and mountains stand and the stars shine. In this manner a proper parceling of the public lands would be made, and at the same time all other scientific purposes of a survey would be subserved.

It is quite unnecessary to represent to a learned body the importance of a good trigonometric survey for scientific purposes. It is rather of its utilitarian purposes that I would here speak, and especially of its importance to our system of surveys of the public lands. Not only would the use of a primary triangulation as the basis of land-surveying remedy the principal defects of that system, but it would be a means of great economy in the final cost, and would have the immense advantage of rendering much of those surveys both unnecessary and inexcusable, and would distribute the cost over the coming years in a manner least burdensome upon the revenue.

The relatively small proportion of the land remaining in the possession of the government which is useful for industrial purposes has had, in the last few years, the effect of locating the incoming population of the far West upon scattered districts where water can be found, and these settlements are separated from each other by mountains or by broad expanses of barren plains which, for many years to come, will not be sold nor turned to any economic use except in very rare instances. And yet a survey is as essential to the title of the homesteader of Wyoming and Idaho as to the old settlers of Ohio and Illinois. To make that survey by present methods, and in conformity with existing statutes, it is necessary to run lines from standard meridians and parallels or from established township corners, and these lines must be "marked and measured" before the contractor can receive his payment. Connections of isolated districts must thus be made through a series of township corners. The futility of marking such corners wherever they may chance to fall in the mountains and deserts, by such perishable devices as are authorized by law, needs no remark. The inaccuracy of such measurements in a difficult country is a consequence equally obvious. The whole system is one which from the peculiar character of the western region renders necessary a very large amount of surveying which serves no useful purpose except to connect isolated districts and such connections are from the nature of the case grossly inaccurate. To such a method the trigonometric method stands in the strongest possible contrast. By a judicious selection of natural and conspicuous geodetic stations scattered over the land, all superfluous surveying may be entirely avoided. The latitudes and longitudes of such stations being once determined, they may become the datum-points or origins of local surveys of all districts which lie in their vicinity. But while a trigonometric survey, if conducted with proper accuracy, is in one sense an expensive undertaking, there may be danger of overestimating its relative cost. It could not be more expensive than the present land surveys which yield such poor and perishable results. But even here it is well to remember that a triangulation, with a secondary and tertiary system of triangles, need not be at once extended over the entire domain, nor even over a very large proportion of it. Population in the far West has shown a tendency to cluster around a number of localities of relatively small extent, while the greater portion of the region is unoccupied. The primary points once determined in a few narrow belts, it will be practicable to expand a net of inferior triangles over those localities which need surveys while the barren wastes may be left until a survey is needed for them. It will always be practicable to regulate the extent of the triangulation, and to adapt it to wants as they arise.

The greatest economy of this method would arise from the fact that it would dispense with the unnecessary work of the present land surveys. Recalling here the fact that under the present method the work is done by contract, it obviously becomes the pecuniary interest of the deputy to survey as much land as practicable provided it will yield him a profit. To a considerable extent he has discretion in the selection of the districts which he has to survey, and being governed solely by considerations of profit, naturally, and quite lawfully, selects such lands as can be surveyed at least cost to himself without regard to their present or even probable occupation by settlers. Many millions of acres have thus been parceled without the slightest necessity, the lands being worthless, and the land marks have been allowed to perish, and all useful results have perished with them. We have but to contrast this prodigal and wasteful method with the permanent and ever-useful results of a triangulation in order to recognize the immense advantage of the latter.

Throughout the Rocky Mountain region, a great portion of the values of the public domain subsist in the mines of gold, silver, cinnabar, lead, &c. The surveys of these mining lands are carried on by methods even more poorly adapted to reasonable requirements than those of the agricultural lands. The tracts of mineral lands containing ores of precious metals, titles to which are conveyed from the general government to individuals, are surveyed by methods so inaccurate that the surveys themselves are of little value in identifying parcels, and in the courts the records of such surveys are of no value, parol evidence being necessarily substituted; for in general the values of the mines exist within narrow horizontal limits and should resurveys be made following original records it would always be probable that sites thus obtained would not coincide with the original one but would be in part or in whole established on other grounds. Under the law the surveys of mineral claims are connected either with the corner posts of the land surveys or with "mineral monuments," and this connection is made by lines run with compass and chain, and it should be remembered that the mines are in the mountains where the use of these instruments involves the greatest expense and secures the least accuracy. To this primitive and almost barbaric system of surveying the mineral lands may be attributed a large part of the disastrous litigation in which the mines of the Rocky Mountain region are involved.

I need scarcely say to a scientific body that such surveys are so inaccurate as to be of no value whatever in determining the position of the claims themselves. It thus happens that when in a mineral district many claims have been surveyed, an attempt is made in the surveyor-general's office, or in the General Land Office in Washington, to plot a number of such claims on a common chart, the several surveys are found to be inconsistent with each other, and overlap or fail to connect. The claims themselves should be plotted on properly constructed topographic charts and be connected with each other by triangulation, and the whole connected with the general system of triangulation which must be carried over the country.

Every mineral district should have a thorough topographic survey, and at convenient points throughout the district monuments should be erected and their absolute and relative positions determined by fixing their angular relations to each other and to the geodetic points of the general triangulation, and thus every miner would have an accurate, simple, and inexpensive method by which the position of his claim could be fixed. But such properly constructed charts necessary for the identification of mineral claims and the proper recording of conveyances would meet all other wants. It would be a sufficient guide to the engineer, for all general purposes, in the location of highways and hydraulic works, and a sufficient map for all scientific purposes. If the work were properly done in the first instance, so as to be sufficient for all reasonable requirements, no duplication of the work would be necessary for any other purpose.

In the administration of the Land Office, there are important facts that should here be considered. The following classes of lands are recognized under the laws:

1. Agricultural lands or lands valuable for agriculture without irrigation or drainage.
2. Swamp lands.
3. Irrigable lands; lands valuable for agriculture only with irrigation and designated in the law as "desert lands."
4. Timber lands.
5. Live-oak and cedar lands.
6. Mineral-vein lands, or lands containing veins or lodes of gold, cinnabar, copper, lead, &c.
7. Placer lands, or lands containing placer mines of the precious metals.
8. Coal lands.

(*Vide* Revised Statutes of the United States, 1878, title 32, chap. 6; title 32, chap. 10, secs. 2458–2468, inclusive; and title 32, chap. 11, secs. 2478–2490, inclusive.

United States Statutes at Large, vol. 19, chap. 107.

Statutes of the United States passed at the second session of the Forty-fifth Congress, chap. 151.)

An examination of the laws thus cited will show that the classes of lands mentioned above are therein recognized, and in the administration of the laws relating to these lands those belonging to each specific class must be determined; but no adequate provision is made for securing an accurate classification, and to a large extent the laws are inoperative, or practically void; for example, coal lands should be sold at ten or twenty dollars per acre, but the department having no means of determining what lands belong to this class, titles to coal lands are usually obtained under the provision of statutes that relate to lands of other classes; that is, by purchasing at $1.25 per acre, or by homestead or pre-emption entry. An examination of the laws will exhibit this fact, that for the classification contemplated therein a thorough survey is necessary, embracing the geological and physical characteristics of the entire public domain

The only provision under the General Land Office for such a survey is contained in the "Instructions to the surveyors-general" (*vide* p. 18, and paragraphs under the head of "Summary of objects and data to be noted.") In the performance of those duties the deputy surveyors, who do the work under contract, fail entirely to provide the facts necessary to the proper administration of the laws, and, in practice, the facts upon which transactions in the department are based are obtained not from experts employed as government officers and competent to perform the task, but on affidavits made by the parties interested, or by persons selected by them, and the history of the Land Office abundantly exhibits the fact that States and individuals have to a large extent obtained titles to lands from the general government under fraudulent representations.

From the above statement, it will be apparent that a thorough survey of the geology and physical classification of the entire domain is necessary to the administration of the laws relating thereto.

The importance of such a survey in the industrial interests of the country requires brief mention. The greater part of the lands yet remaining in the possession of the general government either needs protection on the one hand from overflow, because of excessive humidity, or irrigation on the other, because of excessive aridity. The utilization of all such lands depends upon the correct solution of great engineering problems. Large portions of the public domain on the Gulf coast are swamp lands; the great river valleys of the South are flood-plains, which must be protected from the waters which periodically flow over them; vast areas of swamp and lakelet lands exist in the region of the great lakes that must be redeemed by drainage; the western half of the United States is comparatively arid; in more than four-tenths of our national area, exclusive of Alaska, agriculture is dependent upon irrigation, and here the lands are to be used only by the utilization of rivers and minor streams that are chiefly fed by the snow-fields of the Rocky Mountains. The rapid migration, which has been greater during the past ten years than in any similar portion of the history of the United States, is pushing, in middle latitudes, quite to the verge of possible agriculture without irrigation, and soon all the lands in the humid and subhumid region belonging to the general government will be exhausted, and future settlers on public domain will be compelled to resort to the lands to be drained or to the lands to be irrigated. On the Floridian peninsula, millions of acres, valuable for the growth of sea-island cotton or sugar, can be redeemed by the drainage of Okeechobee Lake; on the Gulf coast, millions of acres of swamp-land can be redeemed by protecting them from tide-water; in the great flood-plains of the South, millions of acres of the richest land of the continent can be redeemed by protecting them from periodic river floods; in the region of the great lakes, millions of acres can be redeemed by the drainage of the swamp and small lakes; and in the Rocky Mountain region, very many millions of acres of land can be redeemed by spreading the rivers over the plains and valleys. Some of the engineering problems thus indicated have important mutual relations. The time must soon come when all the waters of the Missouri will be spread over the great plains, and the bed of the river will be dry. A large part of the Arkansas must also be taken out to fertilize the lands adjacent to its upper course, and still farther south the waters of the upper ramifications of the Red River must be used. The utilization of these waters flowing during the season of irrigation, and the storage of the surplus, will have an important effect upon the Mississippi River, and will, to some extent at least, relieve the great valley plains of the Mississippi, extending from the mouth of the Ohio to the Gulf of Mexico, from the devastating floods to which it is periodically subject. It has been pointed out, and it is well known to the scientific men of the country, that the present system of protecting these lands by levees is not only excessively expensive but entirely inadequate, and it has been further shown that it is practicable to redeem these lands by the storage of the waters. (*Vide* Ellet: Physical Geography Mississippi Valley. Smithsonian Contributions to Knowledge. Vol. II.) But if the excess of waters can be used for irrigation a double purpose will be accomplished, and if the relief thus obtained is quantitatively insufficient, a thorough investigation of the subject should be made, for the purpose of determining what additional measures can be adopted that will be efficient and economic.

Again, in the arid region of the United States, which is more than four-tenths of the whole area, as had been stated, but a comparatively small portion can be redeemed by irrigation, and what remains is not of much value. It is, considering the wants of the country, in the main bountifully supplied with timber, but the timber is not distributed on or adjacent to the agricultural lands; it is found on the high plateaus and mountains where climatic conditions make agriculture impossible. Between the elevated timber regions and the irrigable lands adjacent to the streams are broad stretches of plain, valley, hill, and mountain-lands valuable to some extent for grazing purposes. These physical characteristics of the country demand further investigation, and the classification of the lands of the public domain now involved in the laws relating thereto must necessarily in the immediate future be somewhat enlarged. For a more thorough exposition of this subject, I beg leave to refer you to my report on the "Lands of the Arid Region of the United States," copies of which I transmitted to the vice-president of the National Academy of Sciences September 24, with the request that the same be distributed among the members of the committee.

The greater part of the remaining public domain is in the far West. The immediate incentives to its settlement are the mines of precious metals found in its mountains. It is a region of vast and inexhaustible wealth, and gold, silver, cinnabar, copper, lead, iron, and coal abound. In the State of Arkansas and the Gulf States east of the Mississippi River, where important portions of the public domain are found, the mountains are great repositories of mineral wealth. In all of these regions a geological survey is necessary not alone to the proper administration of the Land Office, but it is of vast importance and of great value to the general government and to the people of the United States by properly exhibiting the character and extent of our mineral resources.

In the statements thus briefly made, I have attempted to indicate by a few illustrations the character of the scientific problems involved in the question submitted by Congress to the Academy of Sciences, and the more important economic considerations that inhere in the subject.

From the statement above, though briefly and imperfectly made, it will be clear that a proper scientific survey embracing the geography of the public domain with the parceling of the lands, and the geology with all the physical characteristics connected therewith, is necessary for the following reasons:

First, to secure an accurate parceling of the public lands and enduring boundary lines.

Second, for the proper administration of the laws relating to the public lands.

Third, for a correct and full knowledge of the agricultural and mineral resources of the lands;

And fourth, for all purposes of abstract science.

These considerations are ample to secure from the National Legislature all necessary financial endowments for the prosecution of the surveys. It should be remembered that the statesmen of America who compose and have composed our National Legislature have been not averse to the endowment of scientific research when such research is properly related to the industries of the people. The verity of this statement will be more apparent by the consideration of the following facts:

For scientific work carried on under the direction of the War Department, the following appropriations have been made:

River and harbor improvements:	
For the fiscal year ending June 30, 1876	$5,900,000
For the fiscal year ending June 30, 1877	4,550,000
For the fiscal year ending June 30, 1879	8,200,000
Signal-service:	
For the fiscal year ending June 30, 1876	507,000
For the fiscal year ending June 30, 1877	349,000
For the fiscal year ending June 30, 1878	326,000
For the fiscal year ending June 30, 1879	404,000
Lake surveys:	
For the fiscal year ending June 30, 1876	150,000
For the fiscal year ending June 30, 1877	100,000
For the fiscal year ending June 30, 1878	110,000
For the fiscal year ending June 30, 1879	99,000

In addition to the direct appropriations mentioned above, large indirect appropriations were made in the bills providing for the support of the Army. In some cases the indirect appropriations were even larger than the direct.

For scientific work carried on under the direction of the Treasury Department, th[illegible] following appropriations have been made:

Coast Survey:	
For the fiscal year ending June 30, 1876	$717,0[illegible]
For the fiscal year ending June 30, 1877, (including deficiency)	626,0[illegible]
For the fiscal year ending June 30, 1878	468,[illegible]
For the fiscal year ending June 30, 1879	547,[illegible]
Weights and Measures:	
For the fiscal year ending June 30, 1876	7,[illegible]00
For the fiscal year ending June 30, 1877	9,[illegible]00
For the fiscal year ending June 30, 1878	4,[illegible]00
For the fiscal year ending June 30, 1879	5,000
Light-House Board:	
For the fiscal year ending June 30, 1876	2,750,000
For the fiscal year ending June 30, 1877	2,470,000
For the fiscal year ending June 30, 1878	2,130,000
For the fiscal year ending June 30, 1879	1,970,000

For scientific work carried on under the direction of the Navy Department, the following appropriations have been made:

Naval Observatory:

For the fiscal year ending June 30, 1876	$20,500
For the fiscal year ending June 30, 1877	21,300
For the fiscal year ending June 30, 1878	28,000
For the fiscal year ending June 30, 1879	23,100

Nautical Almanac:

For the fiscal year ending June 30, 1876	24,500
For the fiscal year ending June 30, 1877	19,500
For the fiscal year ending June 30, 1878	19,500
For the fiscal year ending June 30, 1879	22,500

For scientific work carried on under the direction of the Interior Department the following appropriations have been made:

General Land Office:

For the fiscal year ending June 30, 1869	$535,000
For the fiscal year ending June 30, 1870, (including deficiency)	575,000
For the fiscal year ending June 30, 1871	790,000
For the fiscal year ending June 30, 1872, (including deficiency)	790,000
For the fiscal year ending June 30, 1873	1,248,000
For the fiscal year ending June 30, 1874	1,365,000
For the fiscal year ending June 30, 1875	1,238,000
For the fiscal year ending June 30, 1876	1,097,000
For the fiscal year ending June 30, 1877, (including deficiency)	550,000
For the fiscal year ending June 30, 1878	474,000
For the fiscal year ending June 30, 1879	535,000

The expenditures under the Land Office have been given for ten years, from the fact that for the past two or three years the appropriations made under this head have been greatly diminished. This diminution was due to the fact that it had come to be recognized by Congress that the surveys were carried on by faulty and wasteful methods.

The items mentioned above are only approximations, as the writer is not able to state exactly what proportion of the office expenditures of the General Land Office should be included under this head. One-fifth of the general expense of maintaining the office has been included.

For scientific work carried on under the direction of the United States Commission Fish and Fisheries, the following appropriations have been made:

For the fiscal year ending June 30, 1876	$53,500
For the fiscal year ending June 30, 1877	36,000
For the fiscal year ending June 30, 1878	51,000
For the fiscal year ending June 30, 1879	51,000

From the several reports made in answer to the resolution of the Hon. J. D. C. Atkins, it appears that the following has been the total cost of the different geographical and geological surveys that have been in progress of late years, up to June 30, 1878, to which is added the appropriation for the fiscal year ending June 30, 1879:

United States Geological Exploration of the 40th Parallel, under Clarence King:

Amount expended up to June 30, 1878 (1868–1872)	$386,711

United States Surveys and Explorations west of the 100th Meridian, under Lieut. Geo. M. Wheeler:

Amount expended up to June 30, 1878 (1869–1878)	$499,316
Appropriation for the fiscal year ending June 30, 1879	50,000

United States Geographical and Geological Survey of the Territories, under Prof. F. V. Hayden:

Amount expended up to June 30, 1878 (1867–1878)	$615,000
Appropriation for the fiscal year ending June 30, 1879	75,000

United States Geographical and Geological Survey of the Rocky Mountain Region, under J. W. Powell:

Amount expended up to June 30, 1878 (1871–1878)	$209,000
Appropriation for the fiscal year ending June 30, 1879	50,000

The above statement of appropriations does not include those made for the Agricultural Department, where scientific investigations are pursued to some extent, nor the many temporary appropriations such as those made for the Polaris expedition, and for investigations relating to steel and iron. It will appear from the above that the direct appropriations made for great national work involving scientific research amount to more than eight and one-half millions of dollars annually; and should we include the indirect appropriations, the amount would be considerably more than ten millions of dollars.

Much of this great amount has not been given directly for scientific research, but all the work performed under these expenditures has involved scientific investigation, and there have resulted therefrom many valuable contributions to knowledge; thus scientific research in many fields has had munificent endowment.

These amounts have been appropriated directly for the purpose of making many of the great industries of the people at large more remunerative and secure, but the history of the legislation connected therewith and the preliminary discussions in the National Legislature abundantly show that the statesmen of the country have not been unmindful of the scientific results which might accrue therefrom, but, on the contrary, such results have received due consideration and have been potent in securing the advocacy of many wise and able men. In submitting a plan to Congress for the organization of a geographical and geological survey, these facts should not be ignored. The survey should be allied to the great industrial interests of the country, those relating to agriculture and mining being of greatest magnitude, and affecting the largest number of people.

A survey organized for the purposes which I have indicated will always receive ample support because the results of its work will increase the national wealth, and beneficially affect the largest proportion of the people. But a geographical and geological survey divorced from these economic considerations, and devoted to research valuable chiefly for abstract science, must always be weak and have an uncertain tenure of existence; for in the efforts made to reduce the expenses of administration and drainage on national revenue such expenditures would be the first to be cut off. *A geographical and geological survey, to be permanent, rigorous, and efficient, should include the survey of the public lands and be subsidiary thereto.*

In the execution of the trust imposed by law on the National Academy of Sciences, two important facts, not having direct mention in the statement above, merit attention.

First. Under the Coast Survey a transcontinental triangulation is now in progress, and much has already been accomplished, as the Coast Survey has a very large number of persons trained as experts in geographical science. Two such systems of triangulation are unnecessary; the one now in progress should be made the basis of all future geographical work in the United States.

Second. The Signal Service Office has already established many stations throughout the country for barometric observations, and these, to a large extent, can be utilized, both in the preparation of hypsometric tables and in the general work, and the results of the data collected by that office are of prime importance in considering many of the questions relating to land economics; hence there should be hearty co-operation between the Signal Service and the geological surveys.

COST OF A GEOGRAPHICAL AND GEOLOGICAL SURVEY.

The average cost of the land surveys, from the time they were instituted to the present, has been something more than twenty dollars per square mile. In the earlie years it was much less; in later much more, for obvious reasons. The mountainou region of the West presents many more difficulties than the plains, prairies, and leve lands of the East. At present, these surveys cost from twenty-five to thirty dolla per square mile, and if the present system continues the cost must steadily increase b cause of increasing difficulties. After a careful consideration of this subject, and son familiarity with the methods and cost of the land surveys and of the geographical a geological surveys of this country, and, to some extent, of those in Europe, I am the opinion that all necessary geographic surveys, including the parceling of t lands, could be made within the expense now incurred for the land surveys. Throug out the western half of the United States all geographic work can be performed at slight comparative cost, on account of certain physical conditions existing there Because of aridity the country is largely destitute of timber, and the presence of ti ber greatly increases the cost of this work; it is also a mountainous country, whe n salient points for triangulation are abundant, and from its numerous elevations the intervening valleys are readily commanded.

For the same reason, viz, excessive aridity, and the destitution of vegetation rest lting therefrom, a geological survey can be carried on at a comparatively slight c st. Not covered by soils and vegetation, the whole country is an open book, where g eological structure and distribution are plainly revealed, and the geologist is often a ble to discover at a single glance from some eminence what in regions favored with a greater humidity would be found out only after weeks or even months of patient toil.

In comparing the cost of the surveys which should be made in this country with those made in Europe, the diverse purposes for which these surveys are made should receive attention. In Europe the areas to be surveyed, in comparison with extent of population and national wealth, are small; in America the areas to be surveyed, in comparison with the population and wealth, are great: in Europe, large standing armies are supported, and the several governments stand ever prepared for war; by those nations which have or are executing the most elaborate surveys, the object is to prepare detailed charts of every possible battle-field within their dominion, which, in fact, embraces the whole area of their territory. The relation of the United States to adjacent nations on the continent is such that our statesmen do not think it necessary to support a large standing army, and in the organization of a survey of the United States it is not necessary to consider this military purpose. We need not construct maps on a scale so elaborate as we should were we compelled to consider the whole area of the country as a succession of battle-fields; but general charts, sufficiently elaborate for economic and scientific purposes, would serve all purposes of military strategy or the planning of campaigns.

In discussing geographic surveys, we may divide the subject-matter into two parts: first, the survey and representation of the natural features, which we may call the *nature* portion of the work; and, second, the survey and delineation of the more prominent works of man upon the surface of the earth; this we may call the *culture* portion. In the surveys made for military purposes this culture part receives relatively enormous attention.

Again, in those countries of Europe where the most elaborate and expensive surveys are executed, the lands are in great part included in large estates which belong to the landed gentry; the few owners are all-powerful in the administration of the several governments, and it is considered by them that the culture of every estate, its forests, its fields, its orchards, its walls, its hedges, its ditches, its buildings, &c., should be a matter of public record; that the extent, characteristics, and appurtenances of every estate should be thoroughly understood, in order that the position and importance of every great family in the social fabric may be clearly set forth. These reasons for an elaborate survey do not exist in this country, and in such a work, carried on by authority of the general government, should receive but slight attention. The position of towns, highways, &c., should be determined and marked, but the vast details of culture should be omitted. The nature part of the survey is permanent; the culture portion in this country is rapidly changing, and if municipalities, townships, counties, or States should desire to prosecute detailed culture-surveys, the proper charts representing the nature portion would be furnished ready to their hands. In fact, these smaller units of our political organization do engage in these enterprises, and many districts, townships, and counties have prepared elaborate charts of their areas; usually, however, neglecting the nature portion of the work.

In the immediate future it is probable that the farm unit in the western portion of our country will be changed, so that it will not be necessary to parcel the public lands into tracts so small as we are now doing under existing laws. This matter I have set forth more fully in my "Report on the Arid Lands of the United States," to which I again beg to call the attention of the committee. Should this change be made, the expense of the land surveys will be materially diminished, and the saving therefrom will probably defray the cost of the geological portion of the work. In this paper, however, I have based my statements wholly on the facts and laws as they now stand.

ZOÖLOGY AND BOTANY.

In considering the broad question of what should be the attitude of a government toward scientific surveys, it is not apparent why the problem should present in this country any greater difficulties than those presented in Europe. It has there been discussed alike by statesmen and by men of science with no difference of opinion as to general conclusions, and among the leading minds very little as to details. It will probably be universally admitted that the endowment of science by governments should be very limited and scrupulously confined to those objects of research which under ordinary circumstances could not or would not be undertaken by individuals. This conclusion does not arise so much from considerations as to what may be the duty of the government as from the fact that the efforts and energies of individuals acting from no other stimulus than the love of science are productive of better results than when acting under the stimulus of government patronage. There can, however, be little doubt that a topographic survey and a general geologic survey are works which fall fully within the class which may and ought to be sustained by the government. It is because of the great magnitude and expense of such undertakings, which place them far beyond the reach of individual enterprise.

But a government which patronizes and sustains such investigations has the unquestioned right to demand in return results which shall be not merely for the benefit the scientific, the learned, and the cultured, but for the immediate use and wants all classes. It has the right to demand not only results of general value, but those utilitarian value. In a popular government like ours these considerations are e more forcible than in those governments where the dominant classes belong to middle and higher orders. A survey in this country, sustained by the governme which does not closely ally itself to those utilitarian demands cannot be strong permanent; nor can it face the public with demands for subsidies, as if they w things of right. These surveys should be both ostensibly and really so closely rela to the practical wants of the people and of the government itself that no quest could ever be reasonably raised against their utility or even necessity. They sh fill in the public scheme a position analogous to those which are filled by the C Survey, Signal Service, Naval Observatory, Agricultural Department, and the Li House establishment. Nor is there the slightest danger that in an organization u such a basis and for such purposes the interests of science would suffer. No objec could be raised even by the most captious against the prosecution of any branc scientific research properly co-ordinated with such a work, on the ground of its b too thorough or too exhaustive. Objections could commence only when such a vey should venture beyond the strict limits of its proper purview, and it mus admitted that objections then could not be commenced too quickly or be made strong.

The liberality which has always been manifested in Congress and in the exec ativ departments towards scientific research is a full guarantee for the present at least an doubtless also for the future, that a survey restricting its action to its proper field, bu prosecuting it to the utmost within that field, will be most liberally provided for and abundantly sustained.

It would, in my opinion, be unadvisable for government to sustain and endow research in the various branches of zoölogy and botany except in a very limited way and for very narrow and special purposes. It may, indeed, often happen that special inquiries in zoölogy and botany may suddenly acquire the importance of questions affecting intimately the national welfare, like the ravages of locusts and the cotton-worm, or subjects relating to the growth and production of forests, and these inquiries may require immediate prosecution at great expense. Such exceptions can always be taken into consideration as they arise. They do not appear to invalidate the general rule here suggested, that zoölogy and botany as branches of general science are not proper subjects of governmental patronage. Perhaps it is safe to take the ground that those sciences are injured rather than benefited by such patronage, unless it is extended in the most cautious and sparing manner, for assured patronage cannot be needed to stimulate such researches. The workers in these fields already number thousands, may it not be safely said tens of thousands, who neither ask nor want the slightest assistance from the government. It is by the numberless tributes of this great throng of seekers after knowledge that the great mass of facts constituting the body of those sciences is accumulated. It is by the master minds in that throng that the broad and philosophic generalizations are evoked, and of these leaders of thought every generation furnishes its modicum. Surely no one will urge that it is the duty of government to add half a dozen workers to the great army of independent investigators, and no one will pretend that any amount of subsidizing can create a single philosopher. The largest amount which Congress could be asked to appropriate would bear but a trifling ratio to the aggregate sum expended by individuals and institutions of learning, either directly or indirectly, in the prosecution of zoölogic and botanic research.

Nor does it seem wise that the government should assume the responsibility and expense of the publication of such works. Magazines, the proceedings and transactions of learned bodies, and books published on the same basis as ordinary literature will afford ample means for making known all discoveries and all generalizations in those branches. Scientific magazines and proceedings will never refuse the publication of contributions, however small, provided they possess real value, and it will hardly be denied that if they do not possess that value they ought not to incumber the literature of science. Nor will means be wanting for the publication of larger and more comprehensive works when their value bears a due proportion to their volume and expense of edition. It may be laid down as a safe rule that works upon zoölogy and botany which are of sufficient value to warrant their publication will ordinarily find the means through existing channels, and those which are of inferior value the government would not be justified in publishing.

The enormous bulk and chaotic character of the literature of these branches is universally felt by naturalists to be a serious evil. Those sciences are heavily encumbered and clogged by the very magnitude of their publications. It will not be supposed for a moment that the entry of the government into the field as a miscellaneous publisher will in any manner affect existing channels of publication, but would merely open another flood-gate. Nor is there any guarantee that its zoologic and botanic works would be more valuable in matter or more concentrated in intellectual nourisht than those which are culled and sifted by scientific periodicals and the commer- publishing-houses.

r such reasons, I do not think it would be wise to include zoology and botany in plan to be recommended to Congress.

ETHNOLOGY.

nlike the subjects last mentioned, there are reasons why ethnologic researches, or stigations relating to the North American Indians, should be fostered by the gen- government. The work is of great magnitude; more than four hundred languages ng to about sixty different stocks having been found within the territory of the ed States. Little of value can be accomplished in making investigations in other ches of the field without a thorough knowledge of the languages. Their sociol- mythology, arts, &c., are not properly known until the people themselves are erstood, with their own conceptions, opinions, and motives. The subjects of study remote from the centers of civilization and culture, and thus inaccessible to the t body of American scholars. The field of research is speedily narrowing because he rapid change in the Indian population now in progress; all habits, customs, opinions are fading away; even languages are disappearing; and in a very few s it will be impossible to study our North American Indians in their primitive con- on except from recorded history. For this reason ethnologic studies in America ald be pushed with the utmost vigor.

ut there are other cogent reasons leading to the same conclusion. In the whole a of the United States, not including Alaska, there is not an important valley un- upied by white men. The rapid spread of civilization since 1849 has placed the te man and the Indian in direct conflict throughout the whole area, and the "In- n problem" is thus forced upon us, and it *must* be solved, wisely or unwisely. ny of the difficulties are inherent and cannot be avoided, but an equal number are ecessary and are caused by the lack of our knowledge relating to the Indians them- es. Savagery is not inchoate civilization; it is a distinct status of society, with own institutions, customs, philosophy, and religion; and all these must necessarily verthrown before new institutions, customs, philosophy, and religion can be intro- ed. The failure to recognize this fact has wrought inconceivable mischief in our nagement of the Indians. For the proper elucidation of this statement a volume ecessary, but I shall have to content myself with some brief illustrations.

mong all the North American Indians, when in a primitive condition, personal perty was almost unknown; ornaments and clothing only were recognized as the perty of the individual, and these only to a limited extent. The right to the soil anded property, the right to the products of the chase, &c., was inherent in the s, or clan, a body of consanguinii, a group of relatives, in some cases on the male e, in others on the female. Inheritance was never to the children of the deceased always to the gens. No other crime was so great, no other vice so abhorrent, as attempt of an individual to use for himself that which belonged to his gens in com- n; hence the personal rights to property recognized in civilization are intensely oxious to the Indian. He looks upon our whole system of property rights as an rmous evil and an unpardonable sin, for which the gods will eventually punish the ked and blasphemous white man.

rom these opinions, inherent alike in their social institutions and religion, arises the iculty which the government has always met in obtaining the consent of the In- ns to the distribution of lands among them in severalty. Tribes have been willing eceive lands and distribute them themselves among their gens. Among those In- ns who have been longest in contact with the white man, as the tribes in Indian ritory and Minnesota, much property has been accumulated, and with the increase their wealth the question of inheritance and individual ownership has at last spon- eously sprung up, and at the present time these tribes are intensely agitated on the ject; the parties holding radical sentiments are rapidly increasing, and it is prob- e that soon, among these tribes, the customs of civilization in this respect will be pted. Among all other tribes the ancient customs are still adhered to with tenac- . In this matter, and many others of a similar character relating to their customs l belief, we must either deal with the Indian as he is, looking to the slow but irre- ible influence of civilization with which he is in contact to effect a change, or we st reduce him to abject slavery.

The attempt to transform a savage into a civilized man by a law, a policy, an ad- nistration, through a great conversion, "as in the twinkling of an eye," or in months, in a few years, is an impossibility clearly appreciated by scientific ethnologists who derstand the institutions and social condition of the Indians. This great fact has t in general been properly recognized in the administration of Indian affairs. A few the wiser missionaries, and a few officers of the Indian Bureau have recognized some the more important facts, but in general they have been ignored.

Again, we have usually attempted to treat with tribes through their chiefs, as if they wielded absolute power; but an Indian tribe is a pure democracy; their chieftaincy is not hereditary, and the chief is but the representative, the speaker of the tribe, and can do no act by which his tribe is bound without being instructed thus to act in due and established form. The blunders we have made and the wrongs we have inflicted upon the Indians because of a failure to recognize this fact have been cruel and inexcusable, except on the ground of our ignorance.

Within the United States there are about sixty radically distinct stocks of Indians. The history of the country shows that no coalition between tribes of different stocks has ever been successful; a few have been attempted, but these have been failures. A knowledge of this fact, and the further knowledge of the extent of the several stocks as they can be classed by linguistic affinities, would be of great value in our administration of Indian affairs. In the late Nez Percé war much fear was entertained lest the Shoshones and Pai Utes of Utah and Nevada would join with the Nez Percés in their revolt, and the officers of the Army, as well as those of the Indian Office, were exceedingly anxious in regard to this matter; and the papers were filled with rumors that such a coalition had been made; the result proved, what had been confidently predicted, that no such alliance could be formed, and the Shoshones and Pai Utes were enlisted to fight against the Nez Percés.

I might continue to illustrate the subject in many ways did time permit, but the foregoing must suffice.

I think it will be apparent from what I have said that a thorough investigation of North American ethnology would be of great value in our Indian Office. The reasons which I have briefly set forth as influencing my opinion that the general government should provide for researches in this field have for many years, to a greater or less extent, been recognized by Congress. Twice in the history of legislation in this country we find that provision has been made, by appropriations, for this work, and it has been discontinued each time only because the character of the researches made failed to obtain the confidence and respect alike of statesmen and scientists. I therefore submit the opinion to the committee that it would be wise to recommend to Congress the continuation of researches in this field, and consider in so doing under what supervision it should be placed to secure wisdom and efficiency in the prosecution. Looking to this end, I would suggest that the Smithsonian Institution has accomplished, in this direction, more than any or all other agencies.

With respect to the last part of the inquiry, relating to the distribution of publications, permit me to express the opinion that, in addition to the number of reports usually ordered by Congress for the use of its members, which experience has shown are in the main wisely distributed, an additional number should be published to be distributed among institutions of learning and public libraries of the United States and to scientific bodies throughout the world for exchange, and a suitable number of extra copies to be sold at cost of paper, press-work, and binding to persons who desire them. This would make the publication of the surveys accessible to the scholars of the country at reasonable rates without detriment to the public revenues. Permit me to point out the fact that the present provision having the same end in view is practically inoperative, because the work must be ordered before publication, and hence before the facts in relation to it are known.

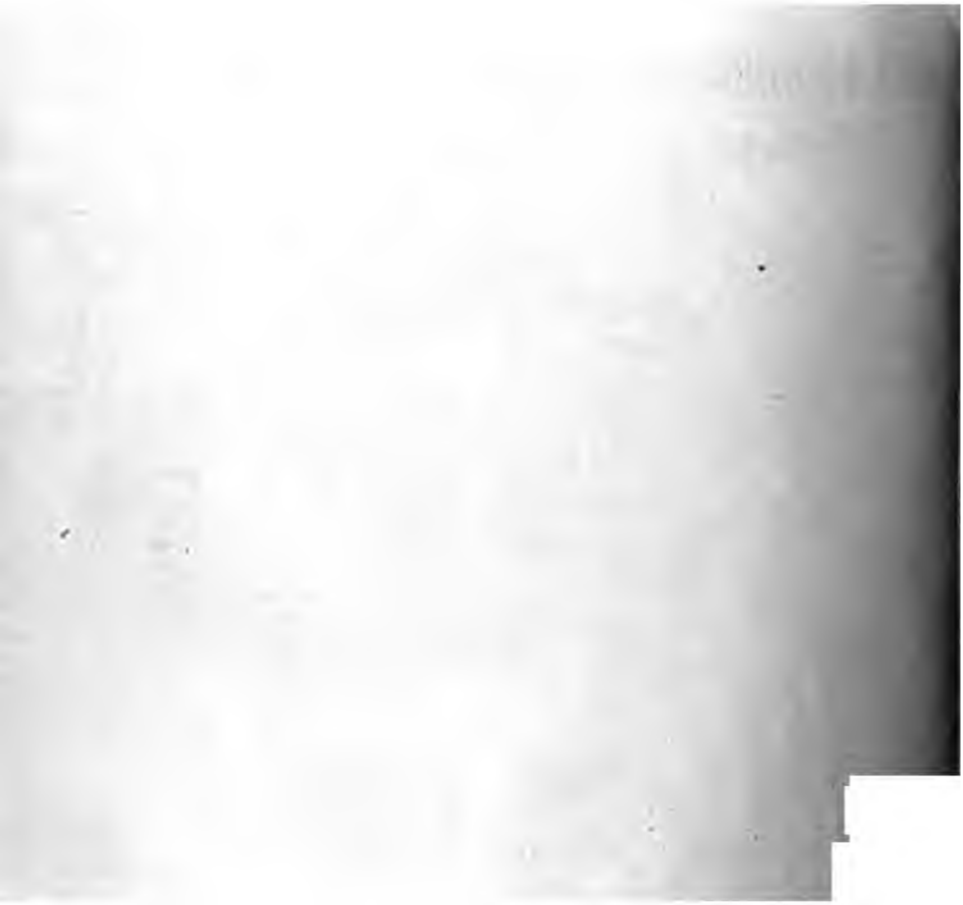
In the above statement I have attempted to recommend no specific plan of organization or specific method of survey, but have attempted simply to set forth some of the more important economic considerations which should receive attention, believing that all scientific aspects will receive due consideration and that mention of the same by myself would be unnecessary.

It is a matter of profound gratification to me that Congress has submitted this important question to the consideration of the body of learned and wise men who compose the National Academy of Sciences, and I am deeply impressed with the honor which has been conferred in calling upon me for this statement of my views.

I am, with great respect, your obedient servant,

J. W. POWELL.

Hon. CARL SCHURZ,
Secretary of the Interior.



MÉMOIRE

SUR

PRIÉTÉS MÉCANIQUES DU BOIS;

PAR

MM. E. CHEVANDIER et G. WERTHEIM.

PARIS,
HELIER, IMPRIMEUR-LIBRAIRE
POLYTECHNIQUE, DU BUREAU DES LONGITUDES, ETC.
Quai des Augustins, 55.

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6490

MÉMOIRE

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LES PROPRIÉTÉS MÉCANIQUES DU BOIS.

Présenté à l'Académie des Sciences, dans sa séance du 5 octobre 1846.

UofM

IMPRIMERIE DE BACHELIER,
rue du Jardinet, 12.

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MÉMOIRE

SUR

LES PROPRIÉTÉS MÉCANIQUES DU BOIS.

Le but de ce travail a été d'étudier les propriétés mécaniques de quelques bois indigènes sous le point de vue théorique et pratique. Nous en avons recherché successivement les lois générales, la marche dans les individus et les variations dues à des différences d'espèce, d'âge, d'exposition et de provenance.

Ce Mémoire se divise en cinq parties : l'*historique de la question*, la *description des appareils* et le *détail des expériences*, le *calcul des expériences* et la *discussion des méthodes employées*, celle des *résultats trouvés*, et enfin les *conclusions*.

PREMIÈRE PARTIE.

Historique.

Les premiers auteurs qui ont étudié les propriétés mécaniques des corps ne se sont occupés que de la cohésion et de la densité, ainsi que du rapport entre ces deux propriétés. La recherche exacte de l'élasticité n'est venue que plus tard, et seulement depuis que la définition de son coefficient a été introduite dans la science par Young et Tredgold.

Relativement aux bois, les auteurs sont tellement en désaccord sur les points les plus essentiels, que, pour en donner une idée exacte, nous ne pouvons mieux faire que de citer textuellement leurs principales opinions, et de réunir dans un seul tableau les résultats numériques auxquels ils sont arrivés pour la densité, la cohésion et le coefficient d'élasticité des différents bois (*voir* tableau n° I) (1).

Parent (*Expériences sur la résistance des bois de chêne et de sapin*, Mémoires de l'Académie des Sciences, 1707 et 1708, page 516) trouve que « la force moyenne du sapin est » à celle du chêne environ comme 358 est à 300, ou comme » 119 à 100. »

Il est bon de remarquer que la plupart des expériences de Parent ont été faites sur des chênes tendres.

Musschenbroeck (*Introductio ad philosophiam naturalem*, Lugduni Batavorum, 1762, tome I) :

Page 409. « La partie des arbres qui regarde vers le nord » est composée, pour la plupart d'entre eux, mais non pour » tous, d'anneaux plus minces, le froid du nord empêchant » l'accroissement et le développement de la végétation ; la » partie exposée au sud se compose, au contraire, d'anneaux plus larges et plus épais : mais j'ai vu quelquefois » le contraire....

» Dans toutes mes expériences, j'ai obtenu les résultats » suivants : la cohésion du cœur de l'arbre est la plus » faible.... A partir du cœur, la cohésion est moindre dans » toute la partie exposée au nord que dans celle exposée au » sud ; la cohésion de la partie exposée à l'ouest est intermédiaire entre ces deux premières, et la plus grande se » trouve dans la partie exposée à l'est. En outre, si l'on

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(1) Nous ne citerons ici que les auteurs qui se sont spécialement occupés des propriétés mécaniques des bois.

» suit le bois à partir du cœur jusqu'à la circonférence, » dans ces quatre directions, le bois le plus solide se trouve » dans un endroit intermédiaire entre l'écorce et la moelle, » et la partie la plus rapprochée de l'aubier dépasse de beaucoup en solidité les parties les plus proches du cœur.

» Il n'y a presque aucune différence de cohésion entre » les parties les plus élevées du tronc placées à l'origine » des branches, et entre les parties voisines du sol; la cohésion ne diffère pas non plus dans le tronc et dans les » branches. Je sais que plusieurs physiciens ont adopté une » opinion contraire; ils prétendent que le cœur de l'arbre » contient le bois le plus dur et le plus ferme; qu'à distance » égale du cœur, et tout autour de lui, le bois est plus » faible, mais de même cohésion, et que l'aubier est la » partie la plus faible; mais je cite simplement ce que » m'ont appris les expériences sur nos arbres....

» Il y a aussi une différence suivant la nature du sol : » les arbres venus dans un terrain sablonneux sont plus » fragiles, tandis que ceux venus dans un terrain argileux » sont plus tenaces. Le bois fraîchement coupé et encore » humide est plus fort que le même bois desséché. »

En général, le travail de Musschenbroeck, quoique un des plus complets, surtout en ce qui concerne les variations de cohésion dans un même arbre, ne repose pas sur des expériences assez nombreuses et assez concluantes pour justifier entièrement les conclusions que nous venons de [illegible] aussi ajoute-t-il lui-même plus loin : « Peut-être n'[illegible] » eu égard à toutes les circonstances qui influent [illegible] » cohésion des bois. »

Buffon (*Œuvres de Buffon*, tome X) :

Page 10. « Le jeune bois est moins fort que le bois plus » âgé : un barreau tiré du pied d'un arbre résiste plus qu'un » barreau qui vient du sommet d'un même arbre; un barreau pris à la circonférence, près de l'aubier, est moins » fort qu'un pareil morceau pris au centre de l'arbre.

» D'ailleurs le degré de desséchement du bois fait beaucoup » à sa résistance; le bois vert casse bien plus difficilement » que le bois sec. »

Page 18. « Le bois qui, dans le même terrain, croît le » plus vite est le plus fort; celui qui a crû lentement, et » dont les cercles annuels, c'est-à-dire les couches ligneuses, sont minces, est plus faible que l'autre.

» J'ai trouvé que la force du bois est proportionnelle à » sa pesanteur; de sorte qu'une pièce de même longueur et » grosseur, mais plus pesante qu'une autre pièce, sera aussi » plus forte à peu près en même raison. »

Page 27. « Le bois, depuis le centre jusqu'à la dernière » circonférence de l'aubier, diminue de densité en progression arithmétique....

» Le bois du pied d'un arbre pèse plus que celui du tronc » au milieu de sa hauteur, et celui de ce milieu pèse plus » que le bois du sommet; et cela à peu près en progression » arithmétique, tant que l'arbre prend de l'accroissement. » Mais il vient un temps où le bois du centre et celui de la » circonférence du cœur pèsent à peu près également, et » c'est le temps auquel le bois est dans sa perfection (ces » expériences ont été faites sur des arbres de 46 à 60 ans); » mais, dans des arbres de 100 à 110 ans, le cœur n'était » plus la partie la plus solide de l'arbre; l'aubier est plus » pesant et plus solide dans les vieux arbres que dans les » jeunes. »

Il est bon de remarquer que le travail de Buffon, bien que fait sur une très-grande échelle, n'a porté que sur le bois de chêne; ce qui ne permettrait pas, ses conclusions fussent-elles toutes démontrées, de les appliquer à d'autres espèces.

Duhamel du Monceau (*Traité de la conservation et de la force des bois*, 1780) :

Page 50. « On doit employer des bois secs.... »

Page 56. « Mais il faut une petite quantité d'humidité

» pour que les bois soient durs; d'où je conclus que les bois » trop secs ne peuvent pas être d'un bon service. »

Page 65. « Le bois qu'on prend dans le pied d'un arbre » est plus pesant que celui de la cime. »

Page 71. « Le bois vert diminue de un tiers de sa pesanteur totale pour être réputé sec au point de produire le » même effet qu'un hygromètre. »

Page 264. « Il paraît que l'extraction de la séve des bois » ne doit point leur faire perdre de leur force, puisque la » séve du bois ne peut augmenter la force qui dépend du » nombre et de la solidité de ses fibres; la séve rend les » fibres ligneuses plus tendres et plus aisées à rompre. »

Page 378. « C'est encore un fait avéré que leurs couches » (les couches ligneuses des mâts qui ont crû dans un pays » très-froid et qui sont de qualité supérieure) sont plus » minces et plus rapprochées les unes des autres. »

Page 411. « Quand les arbres sont vigoureux et qu'ils » végètent encore avec force, c'est le bois du cœur qui » est le plus dense, et dans les gros arbres qui commencent à entrer en retour, le bois du cœur est souvent » plus léger que la couronne qui est entre le cœur et la » circonférence; de sorte que le bois acquiert peu à peu sa » densité, et qu'il la perd peu à peu quand il a passé le » terme de cette plus grande densité. »

Page 438. « Les terrains qui sont les plus propres pour » former de beaux arbres ne sont pas ceux qui les donnent » de la meilleure qualité. »

Page 458. « Dans ces gros pins (pins du Nord de 260 ans » environ), le bois qui a le plus de force est celui qui, en » divisant le diamètre de l'arbre du centre vers la circonférence, jusqu'à l'aubier inclusivement, en six parties » égales, se trouve dans la cinquième partie; mais on » conçoit que cela est sujet à varier suivant bien des circonstances. »

Les trois auteurs dont nous venons de citer des extraits sont presque les seuls qui se soient occupés des différences de densité et de cohésion, existant dans un même arbre, et de l'influence du terrain. La divergence de leurs opinions a laissé ces grandes questions indécises. Elle est peut-être due en partie au peu de constance et de précision dont les expériences de rupture sont susceptibles.

Nous passons sous silence les recherches que Duhamel a faites sur l'influence des fentes, et sur celle que le rapport entre la compression et l'allongement des fibres exerce sur la résistance totale des pièces soumises à la flexion.

Les auteurs postérieurs se sont surtout occupés de l'étude de l'élasticité des bois.

Girard (*Traité de la résistance des solides*, 1798, p. 183), d'accord en ce point avec Perronet (*OEuvres de Perronet*, 1782, tome I, Mémoire sur les pieux et pilotis, page 93), conclut de l'ensemble de ses expériences, que l'élasticité du chêne est à celle du sapin comme 63 est à 47 : il dit, du reste (page 159), que la continuité d'action de la même charge augmente la flèche de courbure ; ce qui ne peut, suivant lui, avoir lieu, à moins que l'élasticité ne s'altère et ne perde à chaque instant une certaine portion de son énergie.

Bélidor (*Architecture hydraulique*, 1782), Rondelet (*Art de bâtir*, 1814), Barlow (*Essay on the strength of timber*, 1817), Ebbels et Tredgold, dans plusieurs ouvrages de ce dernier, et surtout dans l'*Art du charpentier*, ont déterminé la densité, la cohésion et le coefficient d'élasticité pour un grand nombre de bois d'espèces et de provenances différentes.

M. Charles Dupin (*Expériences sur la flexibilité, la force et l'élasticité des bois*, Journal de l'École Polytechnique, tome X, 1815) a publié un grand travail sur les propriétés mécaniques des bois. M. Dupin recherche la nature de la courbe élastique, la position de la fibre invariable ; il vérifie les formules qui expriment les rapports entre les dimensions des pièces, les poids appliqués et les flèches produites.

Page 142. Il prouve que « les courbures des bois, pro-
» duites par des poids très-petits, sont proportionnelles
» à ces poids; » et, page 150, il conclut d'un tableau comprenant le chêne, le cyprès, le hêtre et le sapin, « que
» les pesanteurs spécifiques croissent en même temps que
» les résistances à la flexion, mais croissent beaucoup
» moins. »

Page 194. M. Dupin fait remarquer que « les forces
» qu'il faut employer pour amener les bois au point de
» rupture n'ont aucune relation nécessaire avec les forces
» qui produisent la flexion des bois.

» Ainsi quelques espèces végétales opposent très-peu de
» résistance à la flexion et beaucoup à la rupture : tels
» sont le hêtre, le noyer, l'orme, le sapin, etc. Quelques
» espèces, au contraire, opposent beaucoup de résistance
» à la flexion et beaucoup moins à la rupture proportion-
» nellement : tels sont le cyprès, l'acajou, etc. D'autres
» enfin présentent à la fois beaucoup de résistance à la
» flexion et à la rupture : tels sont le pin de Corse et le
» chêne. »

Ce classement conduit M. Dupin à indiquer le meilleur emploi de ces différentes espèces de bois dans la pratique.

Bevan (*Philosophical Transactions*, 1829) s'est surtout occupé de la détermination du module d'élasticité au moyen de la torsion.

Savart (*Mémoires de l'Académie des Sciences*, 1830) s'est servi des lignes nodales produites par les vibrations sonores de plaques coupées, suivant différentes directions, dans un même morceau de bois de hêtre, pour déterminer les différences d'élasticité et la position des axes d'élasticité dans le bois.

Il fait remarquer, page 404, « que, dans les bois où les
» couches annuelles sont à peu près cylindriques et con-

» centriques, l'élasticité est sensiblement uniforme, suivant toutes les diamétrales d'une section quelconque » perpendiculaire à l'axe de la branche. »

Page 417. « Chaque verge peut faire entendre deux » sons pour un même mode de division, selon que l'ébranlement a lieu suivant sa largeur ou son épaisseur; mais » lorsqu'elles sont très-minces, la différence qui existe » entre eux est assez légère pour qu'on puisse la négliger. »

Savart admet trois axes : le premier, parallèle aux fibres; le deuxième dans le sens du rayon, et le troisième tangentiel aux couches ligneuses; et il trouve, par des expériences faites sur de petits barreaux pris dans le sens de ces trois axes, que, si l'on prend pour unité la résistance à la flexion, dans le sens de la tangente, elle est de 2,25 suivant le rayon, et de 16 suivant l'axe.

Suivant M. Wheatstone (*Philosophical Transactions*, 1833, page 608), « si l'on prépare une plaque de bois de » manière à ce que ses fibres soient parallèles à l'un des » côtés, les axes de plus grande et de plus petite élasticité » seront rectangulairement disposés et parallèles aux côtés » adjacents....

» Si la plaque de bois est un rectangle dont les côtés » soient en raison inverse des carrés de leurs résistances à la » flexion, les deux modes de vibrations parallèles aux côtés, » quoique leurs longueurs soient différentes, seront isochrones, et leur coexistence donnera lieu à une figure » résultante ayant des lignes parallèles à la diagonale. »

On pourrait donc, en recherchant par tâtonnement les longueurs relatives à donner à ces côtés, trouver le rapport des coefficients d'élasticité dans deux directions perpendiculaires.

M. Poncelet (*Mécanique industrielle*, 1839, page 316) entre dans des détails très-complets sur l'élasticité des bois, et surtout sur les expériences par allongement. Il fait voir, d'après les expériences de MM. Minard et Désormes, et celles de M. Ardant, que, pour les premières charges, les allongements sont sensiblement proportionnels aux efforts de tension, et il calcule, d'après ces allongements, des coefficients d'élasticité qui sont compris dans notre tableau n° I.

La limite d'élasticité pour le chêne, d'après les expériences de MM. Minard et Désormes, correspond à une charge de 2$^{\text{kil}}$,13 par millimètre carré, et à un allongement de 0,0016 de la longueur primitive.

Cette limite pour le sapin des Vosges, d'après les expériences de M. Ardant, correspond à une charge de 1$^{\text{kil}}$,85 par millimètre carré, et à un allongement de 0,00117.

Ces divers résultats concernent l'élasticité dans le sens de la longueur des fibres, et, en les rapportant, M. Poncelet exprime le vœu que des recherches analogues soient faites relativement à la résistance élastique dans le sens perpendiculaire et dans le sens tangentiel aux couches ligneuses.

D'après M. Eaton Hodgkinson (Combes, *Exploitation des Mines*, tome I, page 550), un raccourcissement de 0,0027 de la longueur primitive des fibres, dans un prisme infléchi, altère très-notablement l'élasticité.

M. Hagen (*Annales de Poggendorff*, t. LVIII, p. 125) a étudié l'élasticité de plusieurs espèces de bois par la flexion de tringles prises dans le sens des fibres et perpendiculairement à celles-ci. M. Hagen n'a trouvé aucune différence bien grande entre le bois de cœur et l'aubier; il a, du reste, reconnu que le coefficient d'élasticité diminue considérablement lorsque le bois est fortement mouillé.

MM. Paccinotti et Peri (*Il Cimento*, 3$^{\text{e}}$ année, 1845) ont publié, postérieurement à l'époque où nous avions commencé ce travail, des recherches précises et détaillées sur l'élasticité des bois, dans lesquelles ils ont eu spécialement pour but de comparer entre elles les différentes méthodes que l'on emploie pour la détermination du coefficient d'élasticité, et de vérifier si l'on retrouve pour les bois les changements de forme successifs sous des charges croissantes, et les rapports entre la densité et le coefficien d'élasticité que l'un de nous avait déjà déterminés pour le métaux.

Ces physiciens ont opéré par les trois méthodes de l flexion, de l'allongement et de la torsion, sur des tringle de bois carrées de 27 à 36 millimètres de côté.

Leurs expériences pour la flexion ont été faites par cinq procédés différents :

1°. En supportant les extrémités des tringles par de coussinets de pierre ;

2°. En plaçant ces extrémités sur des poulies de bronz mobiles autour d'un axe horizontal ;

3°. En les plaçant sur des cylindres fixes en laiton ;

4°. En ajoutant aux extrémités des tringles des plaques métalliques mobiles autour d'un axe, porté lui-même par un étrier suspendu à des chaînes ;

5°. En encastrant solidement l'une des extrémités.

Ces auteurs ont mesuré, sous des charges croissantes, les allongements tant élastiques que permanents, les angles de torsion successifs, et, dans les expériences de flexion, les ordonnées correspondantes aux différents points de la tringle prise pour axe des abscisses.

Dans la seconde partie de leur travail, MM. Paccinotti et Peri comparent les chiffres résultant de leurs expériences avec ceux qui se déduisent des formules connues, et cherchent à établir une relation entre la densité et le coefficient d'élasticité des bois qu'ils ont examinés.

Ils arrivent ainsi aux conclusions suivantes :

« 1°. L'élasticité produit, dans les différentes parties des
» bois, des changements proportionnels aux forces em-
» ployées, non-seulement pour les premières charges, mais
» aussi pour celles qui sont très-voisines de la rupture.
» pourvu qu'on ait soin de ne pas comprendre, dans l
» mesure de l'élasticité, l'altération permanente due, soi

» à la mollesse de la substance, soit à la permanence de » la charge.

» 2°. Les courbes que prennent les bois encastrés par » une extrémité, toutes choses égales d'ailleurs, ne sont » pas les mêmes que celles que prendraient les mêmes bois » soutenus aux deux extrémités ; ce qu'il faut attribuer à » la réaction des fibres dans les deux branches opposées. » Cependant la même théorie peut servir à déterminer ces » deux genres de courbes, pourvu que, dans l'intégration » de l'équation différentielle, on ait égard à la détermination des constantes (dont la valeur dépend du degré » de fixité de l'encastrement).

» 3°. Les différences qui se sont présentées dans la détermination du coefficient d'élasticité disparaissent presque complétement, si l'on désigne par ce nom la quantité $E' = \frac{E}{G}$; E étant la valeur généralement admise jusqu'ici pour le coefficient d'élasticité, et G le poids spécifique.

» 4°. Le coefficient d'élasticité E' est, en général, 2000 » par millimètre carré de section, quoiqu'il y ait quelques » différences entre les diverses espèces de bois.

» 5°. On peut déterminer le coefficient d'élasticité, non-seulement par l'allongement, mais encore par la flexion » et la torsion ; mais on obtient par ces différentes méthodes des valeurs différentes, et, pour les ramener à » un même chiffre, on aura à déterminer dans chaque cas » un coefficient constant dépendant de l'opération elle-même.

» 6°. La méthode la plus facile pour obtenir le coefficient » d'élasticité est de soutenir le solide par les deux extrémités et de le charger par le milieu. »

Les observations de MM. Paccinotti et Peri paraissent aussi exactes qu'elles pouvaient l'être sans l'emploi du cathétomètre : aussi la loi des changements de forme contenue dans la première de leurs propositions est-elle parfaitement conforme à celle qui a lieu pour les métaux. Mais il reste quelque incertitude quant aux coefficients déduits de ces expériences et quant à la comparaison des méthodes entre elles; car ces auteurs ont négligé de tenir compte, tant de la partie de l'arbre dans laquelle les tringles avaient été prises, que du degré d'humidité de celles-ci dans les différentes expériences auxquelles elles ont été soumises. On verra, dans la suite de ce travail, que l'élasticité n'est pas la même dans toutes les parties d'un arbre, qu'elle change notablement avec le degré d'humidité, et que cette dernière est elle-même très-variable dans des tringles minces comme celles dont les auteurs se sont servis. Les résultats des observations que MM. Paccinotti et Peri ont faites dans différentes conditions sur un même bois, et de celles qu'ils ont faites sur diverses espèces de bois, ne sont donc pas tout à fait comparables entre eux.

Nous ferons remarquer, en outre, que, d'après les formules connues qui lient entre eux le coefficient d'élasticité et la vitesse du son, le coefficient E', que MM. Paccinotti et Peri ont introduit, est une quantité proportionnelle au carré de la vitesse du son; d'où il suit que, si E' était constant, la vitesse du son devrait être la même pour toutes les espèces de bois. Or on verra bientôt qu'elle varie non-seulement pour les diverses essences, mais encore dans les différentes parties d'un même arbre, et dans une même tringle suivant son degré de dessiccation. Cela se comprend facilement, du reste, puisque le coefficient d'élasticité E augmente en général, par suite de la dessiccation, tandis que le poids spécifique G diminue : $E' = \frac{E}{G}$ doit donc augmenter à fortiori.

Nous terminerons cet aperçu historique des recherches faites jusqu'à ce jour sur les propriétés mécaniques des bois par le résumé des opinions des auteurs sur les questions qui nous ont paru les plus essentielles à résoudre, et qui ont servi, pour ainsi dire, de cadre aux recherches que nous avons entreprises nous-mêmes.

Voici ces questions dans leur ordre le plus naturel :

I. *Quel est l'effet produit sur les bois par des charges successivement croissantes? D'après quelles lois ont lieu les changements de forme qui en résultent, et quelles sont les méthodes applicables aux bois pour la détermination de leurs propriétés mécaniques?*

M. Charles Dupin a démontré la proportionnalité entre les charges et les effets produits lorsque ces premières sont très-petites.

MM. Paccinotti et Peri ont vérifié que cette loi est également vraie pour toutes les charges, même celles qui sont voisines de la rupture, pourvu que l'on tienne compte des changements de forme permanents. Ils ont, de plus, trouvé que, pour faire concorder entre eux les résultats donnés par les différentes méthodes, il faut employer certains coefficients de correction.

II. *Ces propriétés varient-elles dans un même arbre suivant l'orientation, c'est-à-dire suivant qu'une partie est exposée à l'un ou à l'autre des points cardinaux?*

Musschenbroeck seul a traité cette question, en n'ayant égard qu'à la cohésion; il trouve qu'elle est la plus forte à l'est, et qu'elle diminue graduellement jusqu'au nord, en passant par le sud et l'ouest.

III. *Ces propriétés varient-elles avec la quantité d'humidité contenue dans les bois?*

Suivant Musschenbroeck et Buffon, la cohésion est plus forte dans les bois verts que dans les bois secs. Duhamel croit, au contraire, que l'extraction de la séve ne doit point leur faire perdre de force.

Enfin M. Hagen a trouvé, par la dessiccation, une augmentation du coefficient d'élasticité.

IV. *Ces propriétés varient-elles dans un même arbre, à la même hauteur, en allant du centre à la circonférence, et suivant quelle loi?*

Relativement à la densité, Buffon a trouvé que, dans les jeunes arbres, elle diminuait en progression arithmétique du centre à la circonférence, et qu'à l'époque de la maturité, la densité était partout à peu près la même; mais il n'a opéré que sur des chênes.

D'après Duhamel, dans les arbres vigoureux, la plus grande densité se trouve au cœur, tandis que, dans les arbres sur le retour, le bois du cœur est souvent plus léger que celui compris entre le cœur et la circonférence.

Relativement à la cohésion, Musschenbroeck trouve que c'est au cœur de l'arbre qu'elle est la plus faible; que, près de l'aubier, elle est plus forte que près du cœur, et qu'elle atteint son maximum dans une région intermédiaire: ce qui s'accorde avec l'opinion émise par Duhamel relativement aux gros pins du Nord.

Buffon, au contraire, a trouvé que la cohésion était plus forte au centre qu'à la circonférence, mais que cette règle cessait d'être vraie pour des arbres de 100 à 110 ans.

Relativement à l'élasticité, M. Hagen n'a trouvé aucune différence bien grande entre le cœur et l'aubier.

V. *Ces propriétés varient-elles, dans un même arbre, avec la hauteur:*

1°. *Dans le sens des fibres, pour chaque couche ligneuse ou pour la tige de l'arbre prise dans son entier?*

2°. *Perpendiculairement aux fibres dans le sens du rayon?*

3°. *Perpendiculairement aux fibres dans le sens de la tangente aux couches ligneuses?*

Suivant Buffon et Duhamel, la densité du bois diminue en allant du pied vers la cime des arbres.

Musschenbroeck n'admet pas de différence sensible, pour la cohésion, entre le bois des branches et celui de la tige, à quelque hauteur qu'il ait été pris. Suivant Buffon, au contraire, la cohésion serait plus forte au pied des arbres qu'à la cime.

Ces résultats ne concernent que la cohésion dans le sens des fibres.

VI. *Quel est le rapport entre les propriétés mécaniques, dans le sens de la longueur des fibres, et dans deux directions perpendiculaires à celles-ci, à différentes hauteurs dans l'arbre?*

Nous n'avons trouvé, à cet égard, que quelques expériences dues à Savart et à MM. Wheatstone et Hagen, qui ont recherché les rapports entre les élasticités à une même hauteur.

VII. *Quelle est l'influence de l'âge des arbres?*

Nous avons déjà cité les opinions des auteurs relativement aux changements qui surviennent avec l'âge dans les propriétés relatives des différentes couches. Quant au bois pris dans son ensemble, Buffon dit, en outre, qu'il augmente de force avec l'âge, mais cette question n'a pas encore été approfondie. Il en est de même pour les questions suivantes.

VIII. *Quelle est l'influence de l'épaisseur des couches?*

Suivant Buffon, le bois qui, dans le même terrain, croît le plus vite est le plus fort; et celui qui croît lentement, et dont les couches ligneuses sont plus minces, est le plus faible.

Duhamel paraît être d'une opinion contraire. Il rappelle que les pins du Nord, qui sont de qualité supérieure, ont des couches ligneuses très-minces : ce qui résulte aussi des intéressantes recherches de MM. Bravais et Martins (*Re-*

cherches sur la croissance du pin sylvestre, Mémoires l'Académie de Bruxelles).

IX. *Quelle est l'influence de l'exposition?*

X. *Quelle est l'influence de la nature du terrain?*

D'après Musschenbroeck, les terrains sablonneux p duisent des bois moins forts que les terrains argileux; d'après Duhamel, les terrains qui sont les plus prop pour former de beaux arbres ne sont pas ceux qui donnent de la meilleure qualité.

XI. *Quels sont les rapports des différentes propriété mécaniques des bois entre elles?*

Buffon a trouvé que la cohésion était proportionnelle à densité; M. Charles Dupin, que les densités croissent même temps que les résistances à la flexion, mais dans moindre rapport.

Ce dernier auteur a prouvé aussi qu'il n'y a pas de re tion constante entre la cohésion et l'élasticité des bois.

XII. *Quels sont les chiffres moyens qu'on peut admett et quelles sont les conséquences qu'on peut en tirer po la pratique?*

On voit, par le tableau n° I, que les expériences fait jusqu'ici ont conduit à des résultats assez divergents po varier entre les limites suivantes :

	Densité.	Coefficient d'élasticité.	Cohésion.
Chêne	de 0,616 à 0,993	de 500 à 1600	de 5 à 1
Hêtre	de 0,600 à 0,811	de 950 à 1483	de 8 à 1
Sapin	de 0,443 à 0,703	de 611 à 1615	de 5 à 9
Pin	de 0,396 à 0,753	de 433 à 1776	de 4 à 8

En admettant même l'exactitude des méthodes, ces grand divergences peuvent s'expliquer par les conditions dans le quelles les observations ont été faites.

Quelle qu'en soit, du reste, la cause, elles démontre assez la nécessité d'une nouvelle étude des propriétés mécaniques des bois, en tenant compte de toutes les circonstances qui peuvent les modifier, et en complétant les recherches théoriques par des expériences faites au point de vue de la pratique.

DEUXIÈME PARTIE.

Description des appareils et détail des expériences.

Dans ce travail, nous avons recherché d'abord les différences qui, pour les mêmes bois, peuvent résulter des variations d'humidité, et celles qui peuvent exister entre les parties d'un même arbre; puis les propriétés mécaniques dans les arbres en entier, en tenant compte des circonstances qui peuvent les modifier; enfin, les propriétés mécaniques des bois de chêne et de sapin débités dans les formes et les dimensions usitées dans la pratique.

Nous décrirons séparément les méthodes et les appareils que nous avons employés pour ces différentes recherches.

Nous nous sommes servis d'arbres venus sur le revers occidental des Vosges, dans les mêmes localités sur lesquelles les travaux forestiers de l'un de nous ont déjà été faits. Ces bois ont été choisis sur environ 4000 hectares de forêts, dans des conditions exactement connues et assez variées, ce qui est impossible lorsqu'on prend au hasard ceux que l'on trouve dans le commerce. Nous avons suivi sur le terrain tous les détails du travail, de manière à apporter le même soin au choix et à la préparation des arbres qu'aux expériences elles-mêmes.

Les principales circonstances auxquelles nous avons dû avoir égard dans le choix des arbres sont, la nature géologique du sol, la qualité du terrain, l'exposition, l'état de la forêt; et en outre nous avons, pour quel uns, recherché l'influence de l'abatage pendant étaient en séve. Les arbres abattus, et destinés aux re ches théoriques, ont été classés (*voir* le tableau n° II vant la nature géologique du sol; chacun d'eux avai d'ailleurs, au moment de l'abatage, un numéro d'or une marque latérale destinée à faire retrouver plus la position primitive de l'arbre, par rapport aux cardinaux.

Ces forêts sont situées dans trois sols différents : l vosgien, le grès bigarré et le muschelkalk, dans cl desquels nous avons pu distinguer des terrains des qualités suivantes : secs et arides, fertiles, fangeux.

Le grès vosgien, seul, nous a présenté des exposi assez variées pour en tenir compte, les deux autre rains ne nous offrant que des plateaux.

Dans chaque situation différente, et afin de reche quelle pouvait en être l'influence, nous avons coupé

GRÈS VOSGIEN :	1 chêne à glands sessiles, 1 hêtre, 1 sapin, 1 pin.
GRÈS BIGARRÉ :	1 chêne à glands pédonculés, 1 chêne à glands sessiles, 1 hêtre.
MUSCHELKALK :	1 chêne à glands pédonculés, 1 hêtre.

Pour reconnaître l'influence de l'âge, nous avons dans le grès vosgien et dans une même localité, des de chênes, de hêtres et de sapins, de grosseurs et c différents.

Nous avons en outre fait abattre quelques individu autres essences qui croissent dans les mêmes forêts. Et e tous ces arbres ayant été coupés hors séve, nous en avons pris quelques autres en pleine séve.

Les chênes et les sapins qui ont servi aux expériences sur les pièces de formes et de dimensions commerciales (*voir* le tableau n° III), avaient, les chênes, plusieurs années de coupe; les sapins, une année. Nous avons indiqué, dans le tableau précité, leur provenance et les différentes conditions dans lesquelles ils avaient végété.

En somme, le nombre des arbres abattus pour nos expériences a été de 94.

Savoir :

Chêne	31
Hêtre	16
Sapin	28
Pin	6
Charme	2
Bouleau	2
Acacia	2
Orme	1
Frêne	1
Sycomore	1
Érable	1
Tremble	1
Aune	1
Peuplier	1

Ces arbres, excepté ceux débités en pièces commerciales et ceux coupés en séve, ont été, après leur abatage, amenés sous un hangar et conservés à l'abri des influences atmosphériques, afin de les maintenir autant que possible dans l'état dans lequel ils se trouvaient au moment de l'abatage.

A. *Recherche des différences des propriétés mécaniques dans un même arbre.*

Cette recherche comprend les questions posées plus haut, du n° I au n° VI; et il résulte de leur énoncé que, pour les résoudre, il fallait étudier les propriétés mécaniques, non-seulement suivant différentes directions dans un même arbre, mais aussi à des hauteurs différentes et dans différentes couches annuelles, en ayant égard à leur exposition aux quatre points cardinaux.

Nous avons choisi, pour ces expériences, deux chênes, deux hêtres, deux sapins et un arbre de chacune des autres espèces. Ces arbres ont été découpés en billes de 2 mètres de longueur, dont chacune, en partant du pied, a reçu, indépendamment du numéro d'ordre de l'arbre entier, un nouveau numéro indiquant sa hauteur dans l'arbre. A la base de chaque bille nous avons enlevé une plaque transversale de 2 centimètres d'épaisseur, perpendiculaire à l'axe, et également numérotée.

Ces billes ont été refendues à la scie (*Pl. I, fig.* 1), de manière à donner trois planches, dont l'une, comprenant le centre, était prise dans la direction nord-sud, et les deux autres, perpendiculaires à celle-ci, dans les directions est et ouest. Nous désignons ainsi les parties de l'arbre qui avaient été primitivement exposées aux points cardinaux correspondants.

Après avoir exactement compté le nombre des couches annuelles comprises dans ces planches, nous les avons refendues elles-mêmes dans toute leur longueur, en suivant le fil du bois, de manière à obtenir des séries de tringles carrées prises dans le centre, au cœur même de l'arbre, et dans les différentes directions, en allant du centre à la circonférence, mais toujours dans les mêmes couches annuelles pour chaque direction. Nous avons eu soin aussi, lorsque nous examinions plusieurs billes d'un même arbre, de prendre, pour chaque bille, nos tringles dans les mêmes couches annuelles, de manière à suivre celles-ci dans toute leur longueur.

Ces tringles avaient la même longueur à peu près que les billes, c'est-à-dire environ 2 mètres; elles ont été parfaitement calibrées au rabot et amenées toutes à des dimensions égales. Chacune d'elles a reçu trois numéros, le premier indiquant l'arbre auquel elle appartenait, le second la bille dont elle a été tirée, et le troisième sa distance du centre : la tringle prise dans celui-ci portait toujours le n° 1. En outre, chaque tringle a été marquée d'une lettre indiquant son orientation.

On a de même pris dans les rondelles, perpendiculaires à l'axe de l'arbre, deux barreaux, l'un suivant le rayon depuis le centre jusqu'à la circonférence, l'autre dans le sens de la tangente aux couches annuelles. Ces barreaux portent le numéro de l'arbre, celui de la bille, et la lettre R ou T, indiquant leur position primitive dans l'arbre. On remarquera que, d'après les expériences de Savart sur les plaques, nous avons pu prendre indistinctement le premier de ces barreaux suivant un rayon quelconque. Le second a été coupé le plus près possible de la circonférence, et dans la partie où le rayon de courbure était le plus grand.

Comme une partie des tringles devait être rompue à l'état de bois vert, afin de déterminer la cohésion à ce degré d'humidité, nous avons été obligés d'en préparer des séries doubles, c'est-à-dire que dans l'épaisseur de chaque planche et dans les mêmes couches, nous avons toujours pris deux tringles immédiatement voisines, qui pouvaient donc être considérées comme identiquement les mêmes. L'une de ces séries a été immédiatement soumise à toutes les expériences, mais en partie seulement à celles de rupture, et les tringles, conservées entières, ont été desséchées à l'étuve. La seconde série n'a été examinée qu'après quelque temps de séjour au laboratoire, en ayant soin de conserver les tringles entières, et a été ensuite desséchée à l'air libre et au soleil, pour être examinée de nouveau.

Nous avons donc étudié les propriétés mécaniques des tringles longitudinales dans quatre états hygrométrique différents.

1°. *Bois vert.* — C'est ainsi que nous désignons les tringle sur lesquelles nous avons opéré immédiatement après le débit

2°. *Bois après quelque temps de dépôt au laboratoire.* — Ces tringles, ainsi que nous l'avons dit plus haut, étaien restées quelque temps au laboratoire, c'est-à-dire dans u local clos et dans des circonstances complétement les mêmes

3°. *Bois desséché à l'air et au soleil.* — Ces tringle avaient été placées pendant un mois au moins dans un bâche munie de châssis, de manière à pouvoir être fermé pendant la nuit ou pendant la pluie, et où elles recevaient l'action directe du soleil et des courants d'air.

4°. *Bois desséché à l'étuve.* — Ces tringles avaient séjourné pendant environ quinze jours dans une étuve fermée, et dont la température restait constamment entre 40 et 50 degrés centigrades.

Voici maintenant comment nous avons déterminé la quantité d'eau contenue dans ces tringles, en admettant que, par suite des précautions prises, l'état hygrométrique était dans chaque cas le même pour celles tirées d'une même bille, ainsi, du reste, que l'un de nous l'avait déjà reconnu dans des circonstances analogues et pour des bois très-secs, par des expériences directes sur la dessiccation des bois de chauffage.

Nous avons pris par doubles pesées le poids absolu de chaque tringle dans ces divers états de dessiccation; ce qui nous a donné les pertes d'eau successivement éprouvées par chacune, et qui se sont trouvées être sensiblement les mêmes pour les tringles d'une même bille. Enfin, pour trouver la quantité absolue d'eau contenue dans les tringles les plus sèches, celles qui avaient été placées à l'étuve, nous les avons sciées transversalement, de manière à obtenir la même quantité de sciure de chacune; nous avons immédiatement recueilli dans un tube très-mince toutes les sciures provenant ainsi d'une même bille, et les avons placées pendant plusieurs jours dans le vide sec, après les avoir préalablement, et à plusieurs reprises, chauffées à 140 degrés, jusqu'à ce qu'elles ne présentassent plus de pertes sensibles. La perte totale nous a donné la quantité d'eau contenue dans les bois desséchés à l'étuve. Nous en avons déduit les quantités d'eau contenues à chaque état de dessiccation, en ajoutant à cette perte les différences de poids que nous avions préalablement constatées. Tous ces résultats sont réunis dans le tableau n° V.

Nous devons toutefois faire observer que les barreaux pris dans les deux sens perpendiculaires à la direction des fibres n'ont été examinés que dans un seul état, celui de la dessiccation spontanée au laboratoire.

Dans chacun de ces états de dessiccation, nous avions à rechercher le poids absolu, la densité, la vitesse du son, les lois de l'élasticité, le coefficient et la limite d'élasticité, l'allongement maximum et la cohésion. Les expériences ont été faites dans l'ordre suivant, et sans interruption, afin d'éviter autant que possible tout changement dans l'état hygrométrique des tringles.

1°. *Densité.* — Nous nous sommes servis de trois méthodes différentes, suivant qu'elles nous offraient le plus de facilité, et aussi quelquefois pour vérifier par l'une les résultats obtenus par les autres.

Ainsi nous avons fait quelques déterminations à l'aide du voluménomètre de M. Regnault; mais notre cathétomètre étant employé à un autre genre d'expériences, nous n'avons pris que peu de densités à l'aide de cette méthode.

Le plus ordinairement, nous avons employé un flacon bouché, de 5 centimètres de hauteur et de 2 centimètres de diamètre, rempli de mercure, et dans lequel nous introduisions deux morceaux de la même longueur, pris aux extrémités de chaque tringle, en ayant soin de les débarrasser autant que possible des bulles d'air adhérentes au bois. Le poids du mercure déplacé et celui des morceaux de tringles nous ont servi à calculer la densité de ceux-ci.

Enfin, lorsque nous avons eu lieu de craindre que la densité ne fût pas la même dans toute la longueur d'une tringle, et notamment pour les barreaux perpendiculaires aux fibres, nous l'avons déduite du poids absolu de la tringle ou du barreau tout entier et de son volume. Ce dernier lui-même a été déterminé en prenant les longueurs sur un mètre étalon, et les largeurs et épaisseurs, en plusieurs endroits, au moyen du sphéromètre. Les mesures ainsi trouvées différaient très-peu, pour les mêmes tringles, par suite du soin avec lequel celles-ci avaient été calibrées. Nous en avons pris les moyennes et nous les avons portées dans le tableau n° XV.

2°. *Vitesse du son.*— Nous l'avons déterminée, pour les tringles, par la méthode de Chladni, au moyen du son longitudinal : après avoir mesuré exactement la longueur de la tringle, l'un de nous la mettait en vibration, en la tenant par le milieu et en la frottant par l'une de ses extrémités, tandis que l'autre reproduisait le même son sur un sonomètre différentiel, accordé exactement d'après un diapason normal. La longueur de corde qui rendait ce son étant ainsi trouvée, nous avons pu calculer le nombre correspondant de vibrations, et, par suite, la vitesse du son dans la tringle.

Quant aux barreaux transversaux, leur peu de longueur ne permettant pas de leur faire rendre des sons longitudinaux, nous n'avons pu trouver la vitesse du son qu'indirectement, au moyen du coefficient d'élasticité déduit des vibrations transversales.

3°. *Lois de l'élasticité.* — Nous avons recherché ces lois par la méthode des allongements, en soumettant chaque tringle, dans trois degrés d'humidité différents (1), à l'action de charges successivement croissantes, et en mesurant, avec le cathétomètre, les allongements tant élastiques que permanents. Nous nous sommes servis, pour ces expériences, de l'appareil employé précédemment par l'un de nous dans ses recherches sur les métaux et les alliages, et les avons conduites jusqu'à la rupture, en suivant la même marche et avec les mêmes précautions. Il serait beaucoup trop long de donner les détails de toutes les séries d'expériences d'allongement que nous avons eu à faire. Nous nous bornons donc à en rapporter quelques-unes dans le tableau n° IV, comme exemples de la manière dont nous avons opéré sur toutes les tringles.

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(1) Les tringles desséchées à l'étuve étaient devenues trop cassantes pour

Nous avons déterminé ainsi à la fois l'allongement élastique moyen produit par une certaine charge, les allongements permanents successifs, et enfin l'allongement maximum. La première de ces données sert à calculer le coefficient, et la seconde à trouver la limite apparente d'élasticité.

Les barreaux coupés perpendiculairement au sens des fibres étant trop courts pour être soumis à l'allongement, nous avons eu recours à la méthode des vibrations transversales. En général, nous nous sommes servis du son le plus grave que rendent des lames libres par les deux bouts, son que l'on produit en tenant le barreau au point où doit se former l'un des nœuds qui existent dans ce mode de vibration, et en agissant avec un fort archet sur le bout le plus rapproché. Chacun de ces nœuds est placé à un quart de la longueur totale, à partir des extrémités. Mais, lorsque le son ainsi produit était trop grave pour être facilement reproduit sur le sonomètre, nous avons employé un des modes de vibration donnant des sons plus aigus avec trois, quatre et même cinq nœuds. Si l'on exprime le nombre de vibra-

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être soumises à l'allongement; toutefois celles en acacia n'ont pas subi la même altération.

tions du son le plus grave par 3^2, les nombres de vibrations correspondants aux autres sons seront donnés, à très-peu près, par les carrés de la série des nombres impairs 5, 7 et 9. Quel qu'ait été le mode de vibration employé, nous avons donc pu en déduire le coefficient d'élasticité au moyen des formules connues. Dans chaque cas, nous avons vérifié le nombre et la position des nœuds au moyen de sable placé sur la face supérieure du barreau.

Nous devons faire remarquer que les substances homogènes seules rendent toujours le même son lorsque l'on fait vibrer transversalement un barreau carré, soit dans le sens de sa largeur, soit dans celui de son épaisseur, tandis qu'il n'en est pas de même pour les bois. Pour ceux-ci, on obtient, en général, un coefficient d'élasticité un peu plus fort, lorsque les vibrations ont été excitées dans le sens des fibres, que lorsqu'elles l'ont été perpendiculairement aux fibres. Toutefois les différences étant pour la plupart fort petites, nous avons pu prendre comme véritable coefficient la moyenne des deux chiffres obtenus dans chaque cas. Toutes les données de ces expériences sont réunies dans le tableau n° XV.

4°. *Cohésion.* — Cette propriété a été déterminée par la rupture des tringles et des barreaux au moyen de la traction, en ayant soin de leur donner une position parfaitement verticale, et de n'augmenter les charges que lentement et sans secousses.

B. *Recherche des propriétés mécaniques dans les arbres en entier.*

Cette recherche, comprenant les questions déjà posées n^{os} V, VII, VIII, IX et X, pouvait être faite, soit sur les tiges entières, soit sur une portion seulement de ces tiges.

Dans le premier cas, il eût été impossible d'étudier l'influence de la hauteur, et il eût été, en outre, très-difficile de modifier constamment l'appareil suivant la longueur, et d'appliquer des formules aux résultats obtenus sur des pièces irrégulièrement coniques, comme le sont les arbres entiers. Si, d'un autre côté, on avait voulu les ramener à une forme régulière, on leur aurait enlevé en grande partie les couches extérieures, ce qui les aurait mis à peu près dans les conditions des pièces employées dans la pratique, et dont nous nous sommes occupés dans la troisième partie de ce travail.

Nous avons donc préféré prendre, pour la comparaison des différents arbres entre eux, des billes de 2 mètres de longueur dans la partie la plus saine et la plus régulière de chaque tige. Quant à l'influence de la hauteur, nous l'avons recherchée au moyen de billes provenant d'un même arbre, et alternant avec celles qui avaient précédemment été réduites en tringles pour le même objet. Ainsi, dans un arbre partagé en six morceaux, les billes n^{os} 1, 3 et 5, à partir de la base, ont été examinées par couches, et les billes n^{os} 2, 4 et 6 l'ont été en entier.

Dans ces expériences, nous n'avons recherché que la densité et le coefficient d'élasticité. En effet, avec des billes de cette longueur, et quelquefois d'un très-fort diamètre, il eût été difficile d'aller jusqu'à la rupture : d'ailleurs les valeurs de la limite d'élasticité et de la cohésion dépendent trop de la manière d'opérer, et sont par leur nature même trop peu précises pour devoir être prises en considération, lorsqu'il ne s'agit que de petites différences, telles que celles que nous recherchions dans cette partie de notre travail.

Les billes ont été écorcées et préparées de manière à avoir une forme cylindrique; ce que leur peu de longueur a rendu facile, en ne leur enlevant qu'une faible épaisseur de bois à la base.

La densité a été déterminée immédiatement avant l'expérience, au moyen du poids absolu, de la longueur et du diamètre moyen. Pour trouver ce dernier, nous avons pris, avec un cordeau et en cinq endroits différents, la triple circonférence de chaque bille, afin d'avoir ainsi des moyennes plus exactes.

Le coefficient d'élasticité a été déterminé par la flexion, au moyen de charges appliquées au milieu des billes dont les extrémités portaient sur deux appuis. Afin que cette opération pût être convenablement faite sur des pièces aussi fortes, il fallait réaliser les conditions suivantes :

1°. Avoir des points d'appui assez solides pour supporter des charges de plus de 10 000 kilogrammes;

2°. Pouvoir mettre de pareilles charges et les enlever avec facilité et sans secousses;

3°. Pouvoir mesurer les flèches obtenues avec une grande exactitude.

Nous nous sommes servis d'un puits conique en maçonnerie, destiné à un tour vertical, et établi dans un terre-plein au-dessus duquel était placé un hangar. L'ensemble de la construction présente ainsi deux étages : le hangar et le puits, séparés, *Pl. I*, *fig.* 3, 4, 5 et 6, par la ligne *ab*. Chacun de ces étages a son entrée à part et facilement accessible, par suite d'un ressaut existant dans le terrain et compris entre les lignes *ab* et *cd*.

Au-dessus du puits, nous avons établi deux piles en pierres de taille portant sur la maçonnerie, à la partie supérieure et à la face intérieure desquelles nous avons encastré des coussinets en fonte *e*, destinés à recevoir les extrémités des billes et d'un diamètre plus grand que celles-ci. Le tout était disposé de manière à ce que les billes portassent de 4 centimètres au moins à chaque extrémité, sans buter contre les parois de la pierre de taille. Nous avons établi dans le puits, pour recevoir les charges, un très-fort plateau rectangulaire *f*, aux quatre angles duquel étaient attachées quatre chaînes *g* réunies à la hauteur du premier étage par un double étrier *h* et *i* pouvant s'accrocher à une forte chaîne à la Vaucanson *l*, au moyen de laquelle le tout était suspendu sur le milieu des billes.

Quatre crics *m*, placés au fond du puits sur un pavé, servaient à soulever le plateau, et deux chaînes de sûreté *n*, scellées dans les piles, étaient destinées à soutenir l'étrier *h*, et les grandes chaînes *g*, lorsqu'on voulait changer de bille, et en même temps à prévenir les accidents en cas de rupture imprévue. Enfin, nous avons placé un cathétomètre sur une large plaque en fonte *o*, portée par une forte poutre en chêne *p*, qui reposait elle-même sur le rebord supérieur du puits. L'observateur, placé sur la maçonnerie, en arrière du cathétomètre, au point *q*, ne pouvait donc, en marchant, déranger la position du niveau d'eau.

Les deux étriers et les chaînes pesaient ensemble	$184^{\text{kil}},5$
Le plateau............................	$846^{\text{kil}},0$

Voici maintenant comment nous avons opéré pour chaque bille :

Le plateau étant porté par les crics, et les chaînes de suspension retenues par les chaînes de sûreté convenablement raccourcies, nous placions la bille sur les coussinets, de manière à ce que son milieu fût exactement à égale distance des deux supports. Un point de repère indiquait ce milieu sur lequel nous posions la chaîne à la Vaucanson, en ayant soin que le repère restât visible entre les deux branches d'un même anneau. Puis, sans prendre aucune mesure, nous accrochions les étriers, nous allongions les chaînes de sûreté, et nous faisions descendre les crics de manière à ce que le plateau et les poids dont il était chargé, et qui avaient été approximativement déterminés par un calcul préalable, agissent sur le milieu de la bille. Cette dernière prenait ainsi une flèche qu'il s'agissait de mesurer, et qui pouvait d'ailleurs être, ou simplement élastique, ou à la fois élastique et permanente, selon la charge employée. Afin de distinguer ces deux espèces de flèches, et d'avoir la flèche élastique que nous recherchions ici, nous avons toujours pris notre première mesure sous l'action de la charge, et la seconde après l'avoir soulevée au moyen des crics. Ces mesures ont été, ainsi que nous l'avons déjà indiqué, prises au cathétomètre, sur le point de repère du milieu de la bille placé aussi bas que possible, afin d'éviter l'effet de la compression. Leur différence nous donnait directement la flèche élastique produite par le poids de la charge, y compris le plateau. En effet, les chaînes, restant suspendues à la bille dans l'un et l'autre cas, formaient un poids constant sans influence sur la différence des flèches mesurées. Toutefois, dans deux expériences, le poids des chaînes étant à lui seul suffisant pour produire la flèche, elles ont été employées comme charge, et décrochées pour prendre la seconde mesure.

Toute cette opération a été répétée deux fois sur chaque bille, de manière à avoir deux mesures de chaque flèche élastique, et à pouvoir en prendre la moyenne. On verra, tableau n° XIV, que ces deux flèches s'accordent très-sensiblement entre elles.

Dans toutes ces expériences, nous avons eu soin de n'employer que des charges suffisantes pour produire de petites flèches de 1 à 2 centimètres, afin de rester dans les conditions pour lesquelles les formules connues ont été établies, et pour que les flèches permanentes ne fussent pas trop considérables. Et d'ailleurs notre instrument donnant jusqu'aux centièmes de millimètre, ces longueurs de flèches étaient suffisantes pour arriver à des résultats exacts.

Nous avons dû aussi tenir compte d'une cause d'erreurs qui paraît avoir été négligée jusqu'à présent, les compressions que subissent les supports, quelque résistants qu'ils soient, toutes les fois qu'on les soumet à une charge considérable. Ces compressions peuvent être de deux sortes différentes, c'est-à-dire disparaître avec la charge, ou persister après que cette dernière a été enlevée. D'après notre manière d'opérer, celles de la première espèce seules pouvaient influer sur nos résultats. Nous les avons préalablement déterminés, pour chaque pile, au moyen de points de repère marqués sur les coussinets, et dont nous avons suivi les déplacements avec le cathétomètre, sous des charges croissantes suspendues à une bille. Ces compressions, de 2 à 3 millimètres au plus, se sont trouvées proportionnelles aux poids supportés, mais un peu différentes pour chaque appui; leurs moyennes nous ont donné les corrections à appliquer aux flèches obtenues, corrections dont la grandeur relative ne permet pas de les négliger.

Enfin, immédiatement après chaque expérience de flexion, nous avons déterminé la quantité d'eau hygrométrique contenue dans la bille, sur de la sciure provenant d'un trait de scie transversal. Cette sciure, qui représentait également toutes les couches, a été parfaitement mélangée, et desséchée dans le vide sec, d'après la méthode déjà décrite.

C. *Recherche des propriétés mécaniques des bois débités dans les dimensions usitées dans la pratique.*

Cette partie de notre travail contient quelques expériences sur des pièces de chêne et de sapin, dans les conditions dans lesquelles les présente le commerce. Nous nous sommes servis de planches et de madriers de ces deux espèces de bois, ainsi que de pièces de charpente de diverses dimensions, depuis les chevrons (pièces de $0^m,08$ sur $0^m,10$ environ) jusqu'aux fortes pannes (pièces de $0^m,23$ sur $0^m,25$ environ), et sur des longueurs de 4 à 7 mètres pour le chêne, et de 10 à 14 mètres pour le sapin. Tous ces bois ont été équarris à vive arête, de manière à présenter des prismes plus réguliers que les pièces habituellement employées. Nous en avons déterminé la densité, et ensuite les propriétés élastiques au moyen de charges successivement croissantes jusqu'à la rupture.

Pour trouver la densité, nous avons pris le poids absolu, la longueur de chaque pièce, et ses autres dimensions de mètre en mètre courant. Les nombres qui expriment ces dernières dans les tableaux nᵒˢ XVII et XVIII sont les moyennes résultant de ces mesures.

Afin de pouvoir, dans les expériences de flexion, appliquer graduellement et sans secousses les charges successives, en évitant tout danger lors de la rupture, nous avons remplacé, pour les pièces, dans l'appareil dont nous nous étions servis pour les billes, les poids en fonte par des charges d'eau faciles à augmenter graduellement du dehors, *Pl. I, fig.* 7 et 8. Nous avons placé sur le plateau, convenablement renforcé, deux foudres *r* de la contenance de 25 hectolitres chacun et destinés à recevoir l'eau. Une pompe, plongeant dans un cours d'eau en dehors de la construction en maçonnerie, servait à amener l'eau à volonté dans les tonneaux, dont on pouvait ensuite la faire sortir au moyen d'un robinet placé à la base. Pour indiquer à chaque moment les quantités d'eau contenues, nous avons ajouté, à chacun des foudres, un flotteur *s* portant une tige *t* graduée à l'avance d'après le jaugeage des tonneaux. Cette tige montait jusqu'à l'étage supérieur, et sa position, par rapport à une règle fixée elle-même sur le tonneau, donnait le nombre de litres. Le plateau était, comme dans les expériences précédentes, supporté par les crics *n* et attaché aux chaînes *g*; mais, pour quelques pièces d'un petit échantillon, l'appareil précédent eût été trop pesant comme première charge. Nous avons, pour ces pièces, attaché l'un des foudres seulement aux chaînes, et comme les flèches prises étaient souvent plus grandes que la course des crics *n*, nous avons remplacé les étriers par un cric à vis. Cette vis, assez forte pour supporter toutes nos charges, était sortie au commencement de l'expérience, et à mesure que le tonneau arrivait au niveau du sol, on la faisait rentrer pour le remonter.

La nécessité d'avoir, pour ces expériences, des appuis de distances variables avec la longueur des pièces nous a fait renoncer aux supports en maçonnerie. Nous les avons remplacés par des piles de fortes poutres en chêne, très-rapprochées les unes des autres ; mais il était essentiel de pouvoir, à chaque instant, mesurer la dépression de ces supports. Pour cela, nous nous sommes servis de deux échelles graduées sur cuivre, et munies de verniers qui donnaient les centièmes de millimètre. Ces échelles étaient portées par des règles *u* fixées dans le sol, tandis que les verniers étaient attachés à la surface inférieure des poutres *v* sur lesquelles reposaient immédiatement les pièces en expérience, et au-dessous de l'axe de celles-ci. La partie supérieure des piles en maçonnerie établies pour les recherches précédentes ayant dû être enlevée, nous avons remplacé les chaînes de sûreté par une moufle *x* attachée à la toiture du hangar ; elle servait à faciliter la pose des pièces, à soulever les grandes chaînes et à les soutenir au moment de la rupture.

	kil
Dans ces nouvelles expériences, le poids des chaînes et des étriers était de..........	197,5
Celui du plateau, de....................	888,0
Celui du foudre *r* avec son flotteur, de......	426,8
Celui du foudre *r'* avec son flotteur, de.....	376,7

Lorsque le tonneau *r* était employé seul, on lui ajoutait un plancher en madriers boulonnés pesant 273 kilogrammes ; le cric qui remplaçait alors les étriers pesait, avec ses boulons, 166 kilogrammes, et les chaînes 147.

La marche des opérations a été à peu près la même que celle décrite précédemment. Après avoir placé de champ la pièce sur les supports, on a pris au cathétomètre la hauteur du point de repère, et directement la position des verniers : ce qui donnait le point de départ indiqué par zéro dans nos tableaux. Ensuite, selon la force des pièces, on a employé comme première charge, soit le poids de l'appareil vide, soit celui des chaînes seulement ; puis on a soulevé l'appareil, et on a pris de nouveau les mêmes mesures pour avoir la flèche totale due à la première charge. On a continué de la même manière pour les différentes charges d'eau que l'on obtenait en faisant agir la pompe. La flèche trouvée dans chaque observation faite sous l'action d'une charg se compose de la flèche élastique et de la flèche permanent due à cette charge; les mesures prises dans l'observatio faite immédiatement après, la charge étant soulevée, donnent directement la flèche permanente, et la différence de deux n'est autre que la flèche élastique. Il est bien entend que la correction donnée par les verniers doit être appliqué séparément à chaque observation.

Dans les charges voisines de la rupture, il y aurait e danger pour les hommes employés à la manœuvre des crics Nous nous sommes donc contentés de prendre la flèch totale, et les dernières charges n'ont pu être comprises dan les calculs faits pour la détermination des coefficients d'élasticité.

Pour les chevrons, les madriers et les planches, le poid seul des chaînes eût déjà été trop grand comme premièr charge. Nous avons donc, *Pl. I, fig.* 9, employé un plateau y chargé à la main de poids de 20 kilogrammes, e que l'on soulevait au moyen de la moufle x, sans dérange la position des pièces. Celles-ci étaient portées par des supports en bois z boulonnés contre les piles en pierre, et asse solides par rapport aux charges employées, pour que nou ayons cru pouvoir, dans ce cas seulement, négliger de déterminer la compression des appuis. Cette détermination n'eût, au reste, conduit qu'à des corrections insignifiantes, eu égard à la grandeur des flèches obtenues. Les planches et madriers, au lieu d'être placés de champ, l'ont été à plat; du reste, la marche de l'opération a été la même.

Dans aucune des expériences de cette dernière série, nous n'avons recherché la quantité d'eau hygrométrique contenue dans les bois, puisqu'ils se trouvaient dans les conditions de ceux habituellement employés, et que nous avions déjà déduit d'expériences spéciales les coefficients des variations dues à l'humidité.

TROISIÈME PARTIE.

Calcul des expériences et discussion des méthodes.

Après avoir décrit les appareils et les procédés que nous avons employés, nous avons à citer les formules qui ont servi aux calculs et à comparer entre eux les résultats donnés par les différentes méthodes.

Quant à la densité, on remarquera que les valeurs obtenues au moyen du volume d'une bille entière sont généralement plus fortes que celles qui ont été déduites des densités des tringles et des couches composant la même bille. Ces différences peuvent tenir à deux causes. Pour pouvoir rendre ces valeurs comparables entre elles, il a fallu les ramener à un degré d'humidité constant pour lequel nous avons choisi 20 pour 100. Or les coefficients qui ont servi à cette réduction n'ayant pu être déterminés que pour des tringles dont les humidités variaient entre 8 et 40 pour 100 environ, il est possible que ces coefficients ne soient pas constants pour des différences d'humidité plus considérables, ou ne s'appliquent pas exactement à celles des billes. D'un autre côté, les tringles ne représentant pas la totalité des couches de la bille, la détermination de la densité de celle-ci, au moyen des densités des tringles, peut ne pas être rigoureuse.

Ainsi que nous l'avons déjà dit, nous avons employé, pour la recherche des propriétés élastiques des tringles, deux méthodes, celle des vibrations longitudinales et celle de l'allongement : la première donne directement la vitesse du son, la seconde le coefficient d'élasticité. Ces deux quantités sont liées entre elles par l'équation

$$E = \frac{v^2 d}{g}$$

dans laquelle

E est le coefficient d'élasticité,
v la vitesse du son,
d la densité.

Et si l'on prend pour unités : pour la longueur le millimètre, pour le poids le kilogramme, pour la vitesse du son la vitesse dans l'air, pour la densité le poids spécifique de l'eau, on a

$$(a) \qquad \log E = 2 \log v + \log d + 1.05130.$$

On peut donc, à l'aide de cette formule, déduire le coefficient d'élasticité des vibrations longitudinales, et, réciproquement, la vitesse du son de l'allongement.

Or on sait que, pour les gaz et pour les métaux, les nombres trouvés par les vibrations sont supérieurs à ceux qui résultent de l'allongement ou de la compression. Nous avons donc dû rechercher si les bois se comportent de même. Cette vérification était non-seulement intéressante au point de vue théorique; mais elle était nécessaire pour pouvoir rendre comparables entre eux les résultats obtenus par l'une ou l'autre des deux méthodes seulement.

Nous avons porté dans le tableau n° VII les résultats obtenus et les rapports entre les deux coefficients d'élasticité et entre les deux vitesses du son pour toutes les tringles qui ont été traitées comparativement par ces deux méthodes. Le premier de ces rapports est évidemment le carré du second. En parcourant ce tableau, on verra que, pour les bois aussi, les vibrations conduisent à des chiffres plus élevés que l'allongement, et que la dessiccation paraît sans influence sur la grandeur des rapports. Nous avons donc pu prendre pour coefficients de correction les moyennes des rapports trouvés à différentes humidités pour les tringles d'une même bille. Pour avoir le coefficient d'élasticité que nous appelons réel, c'est-à-dire celui qui serait résulté de l'allongement, il faut diviser le coefficient d'élasticité déduit des vibrations par le premier de ces coefficients; tandis qu'il faut multiplier par le second la vitesse du son déduite de l'allongement, pour avoir la vitesse réelle du son. Ces coefficients de correction sont, à peu de chose près, les mêmes pour des billes provenant de la même essence.

Les mêmes coefficients doivent encore s'appliquer aux résultats trouvés par des vibrations transversales, car on sait que celles-ci donnent les mêmes valeurs que les vibrations longitudinales. On en déduit donc le coefficient d'élasticité réel au moyen de la formule

$$\log E = \log p + 2 \log n + 3 \log l - 3 \log a - \log b - 4.02104 - \log c.$$

dans laquelle

p est le poids absolu du barreau,
l sa longueur,
n le nombre de vibrations transversales doubles par seconde,
a le côté de la section suivant lequel on fait vibrer le barreau,
b l'autre côté,
c le coefficient de correction pour les coefficients d'élasticité dans la bille dont le barreau a été tiré.

Pour trouver la vitesse réelle du son, il faut substituer dans la formule (a) la valeur non corrigée de log E.

Nous avons déjà exposé comment nous avons été amenés à employer, pour la détermination des propriétés des arbres en entier et pour la comparaison des différentes essences, des billes cylindriques de 2 mètres seulement de longueur. Cette disposition permet de travailler sur des pièces de forme régulière, dans leur état naturel et en conservant toutes leurs couches; mais, d'un autre côté, on n'est plus dans les conditions pour lesquelles les formules ont été établies. On sait, en effet, que ces formules ne sont rigoureusement applicables qu'à des pièces parfaitement homogènes, tandis que, dans les arbres, l'élasticité varie de couche en couche d'après une loi que nous avons bien pu reconnaître pour chaque bille en particulier, mais qui, comme on le verra plus tard, peut changer avec l'âge et la nature même des arbres. En outre, ces formules n'ont encore été vérifiées que pour des billes d'un diamètre peu considérable par rapport à leur longueur, et non pour de forts diamètres, tels que ceux que nous avons rencontrés dans le cours de nos expériences. Nous avons donc dû nous borner à ne produire que de petites flèches, pour nous écarter le moins possible des conditions du problème, et nous avons cherché, sur un certain nombre de billes, à contrôler les résultats donnés par la flexion, en les comparant à ceux obtenus par allongement sur des tringles prises dans différentes couches de ces billes elles-mêmes.

Les coefficients moyens d'élasticité pour les billes ont été déduits des flèches trouvées par la formule ordinaire

$$(b) \qquad E = \frac{2Pa^3}{3\pi f r^4},$$

dans laquelle

P désigne la charge en kilogrammes,
a la moitié de la distance des appuis,
f la flèche élastique,
r le rayon de la bille.

Nous avons porté dans le tableau n° XVI les coefficients ainsi obtenus et ramenés à 20 pour 100 d'humidité, à côté de ceux qui, résultant de l'allongement des tringles, ont été calculés pour les billes entières, ainsi que nous le dirons plus tard. On voit par ce tableau que, malgré quelques différences, les nombres s'accordent assez bien pour qu'on puisse, en général, suivre cette marche, surtout lorsqu'il ne s'agit que de comparer entre eux des arbres de la même espèce. Ce résultat est encore confirmé par ce qui a eu lieu pour des billes prises à différentes hauteurs dans un même arbre, et soumises, les unes à la flexion, les autres à l'allongement. Les chiffres trouvés suivent la même progression, et ne présentent que des différences d'un ordre tel, qu'elles peuvent être attribuées à la hauteur dans l'arbre.

Les arbres résineux offrent seuls une anomalie remarquable. Tous les coefficients résultant de la flexion des billes, et surtout de celles dont le diamètre était le plus fort, se trouvent beaucoup trop petits lorsqu'on les compare non-seulement aux chiffres obtenus par l'allongement, mais même à ceux qui résultent des expériences de flexion sur des pièces équarries d'une assez grande longueur. Il est donc évident que la formule citée plus haut ne peut pas s'appliquer à des billes de ces essences; ce qu'il faut peut-être attribuer à un manque d'adhérence suffisante et de réaction entre les couches annuelles, et à ce que les couches les plus fortes se trouvent à la circonférence, ainsi qu'on le verra bientôt. Nous n'avons donc pas compris dans nos moyennes générales les résultats des expériences de flexion sur les billes des conifères, bien que nous en ayons donné tous les éléments afin que, si l'on arrive plus tard à modifier les formules, on puisse en tirer des résultats exacts.

Pour les grandes pièces de chêne et de sapin débitées dans les formes du commerce, nous avons pu nous servir des formules qu'on emploie habituellement, et qui ont déjà été suffisamment vérifiées. Nous avons déduit le coefficient d'élasticité de la flèche moyenne, déterminée par un assez grand nombre de mesures, au moyen de la formule

$$(c) \qquad E = \frac{2\,Pa^3}{fbc^3},$$

dans laquelle b est la largeur et c la hauteur de la pièce, c'est-à-dire la dimension dans le sens de laquelle la charge agit.

Dans les formules (b) et (c), on n'a pas eu égard au poids de la pièce elle-même, puisque, les flèches étant prises par différence, ce poids fait partie de la charge permanente.

La résistance à la rupture par millimètre carré de section a été calculée, pour ces pièces, par la formule

$$R=\frac{3[P(a^2+1,5f^2)+\Pi(a^2+3f^2)]}{abc^2},$$

dans laquelle P, a, b, c et f ont les mêmes significations que dans les formules (b) et (c), et Π représente le poids de la partie de la pièce comprise entre les appuis, et qui a pu être facilement calculé d'après le poids et la longueur de la pièce entière et d'après la distance des appuis.

Enfin, la cohésion moyenne pour toutes les essences a été déterminée au moyen de la rupture des tringles par traction; et l'on verra que, pour le chêne et le sapin, elle s'accorde bien avec les valeurs trouvées au moyen de la rupture par flexion.

QUATRIÈME PARTIE.

Discussion des résultats.

Nous avons indiqué, en commençant ce Mémoire, la marche qui nous semblait la plus naturelle, et que nous nous proposions de suivre pour l'étude des propriétés mécaniques des bois.

Avant tout, nous avions à rechercher comment ils se conduisent lorsqu'ils sont soumis à des forces extérieures appliquées de différentes manières, et d'après quelles lois ont lieu les changements de formes produits; car il était possible que ces changements ne fussent pas proportionnels aux forces employées, et, dans ce cas, la définition ordinaire du coefficient d'élasticité n'aurait pas été applicable.

En outre, les premières charges auraient pu produire des altérations suffisantes dans les fibres pour modifier leurs propriétés et en changer les lois. Ce n'était donc qu'après avoir vérifié si les lois et les formules connues s'appliquaient aux bois, que nous pouvions rechercher comment les propriétés mécaniques varient dans les diverses parties d'un même arbre.

Ici, la première question qui se présentait était de s'assurer si l'orientation des différentes parties d'un arbre influe réellement sur leurs propriétés; et, en opérant sur des tringles choisies dans une même couche annuelle, mais à des orientations différentes, cette vérification pouvait se faire avant de connaître l'influence de la quantité d'eau hygrométrique, pourvu que l'on n'employât que des tringles prises dans les mêmes conditions. Il était indispensable ensuite de déterminer cette influence de l'humidité sur le volume et sur les propriétés mécaniques, et de l'exprimer par des coefficients, pour pouvoir rendre comparables les résultats de toutes les expériences qui nous restaient à faire en les ramenant à un degré d'humidité constant.

Dans ces expériences, nous avions à étudier la marche des propriétés mécaniques dans des couches placées à différentes distances du centre, dans les mêmes couches à différentes hauteurs, et enfin dans des directions différentes; puis à rechercher, pour des arbres de la même espèce, l'influence de l'âge, de l'exposition et de la nature du terrain.

Les propriétés mécaniques étant ainsi déterminées pour chaque essence, nous avions enfin à établir les relations qui peuvent exister entre elles, et à déduire toutes les conséquences pratiques, résultant de notre travail.

On trouvera dans les tableaux joints à ce Mémoire tous les éléments de nos expériences ainsi que les résultats des calculs. On verra que, pour chacune des questions que nous

nous étions posées, nous avons été amenés à faire un grand nombre d'expériences portant principalement sur les essences les plus communes dans la localité où nous opérions. En effet, dès qu'on a affaire à des corps organisés, les lois ne peuvent plus se déterminer par des recherches faites sur un seul individu, à cause des différences d'organisation que ces corps présentent toujours. Dans les bois en particulier, l'irrégularité de l'accroissement, les changements d'épaisseur et de direction qu'on rencontre quelquefois dans les couches, les nœuds et d'autres circonstances encore qu'on ne peut prévoir à l'avance, ni même toujours constater, sont autant de causes d'irrégularité dans les chiffres. Aussi, sans nous arrêter à quelques exceptions particulières, avons-nous dû chercher à reconnaître, dans l'ensemble des faits, les lois générales qui les régissent. Nous espérons y être arrivés d'une manière suffisante pour la plupart des questions relatives aux différences dans les individus et dans les espèces; mais nous n'avons pu résoudre complétement les questions relatives aux influences locales qui auraient exigé des expériences encore plus nombreuses que les nôtres, et faites dans des localités et des climats différents.

Après ce court exposé des considérations qui nous ont guidés, il nous reste à faire connaître et à discuter les résultats auxquels nous sommes arrivés :

I. On verra, par les expériences d'allongement rapportées comme exemples dans le tableau n° IV, que, pour les bois comme pour les métaux, on peut et l'on doit distinguer deux espèces d'allongement, l'allongement élastique et l'allongement permanent, et que le premier est très-sensiblement proportionnel aux charges. Le premier des allongements mesurés est quelquefois un peu en désaccord avec les autres, quoique nous ayons eu soin, avant de prendre la première mesure, de charger les tringles d'un poids suffisant pour en opérer le redressement, et qui, par conséquent, n'a pas été compris dans la charge produisant l'allongement élastique. Du reste, la même chose a également lieu pour les métaux.

Quant aux allongements permanents, on verra qu'ils commencent presque toujours dès les premières charges, et qu'ils croissent d'une manière irrégulière avec celles-ci; ce qui s'explique facilement, puisqu'ils dépendent non-seulement de la grandeur de la charge, mais encore de sa durée et de la manière d'opérer. En outre, dans un certain nombre de cas, ces allongements diminuent après plusieurs charges, au lieu d'augmenter, pour ensuite reprendre leur marche ordinaire. Ces espèces de ressauts qui se présentent aussi, mais moins fréquemment, dans les métaux, paraissent être dues à une contraction brusque et irrégulière des fibres, par suite de l'enlèvement de la charge. Il résulte de ces considérations, qu'on ne saurait attribuer, en théorie, une valeur déterminée ni à la limite d'élasticité, ni à l'allongement maximum. Aussi n'avons-nous pas spécialement recherché ces données dans nos expériences. Toutefois, comme dans leur acception ordinaire, on peut les déduire des allongements mesurés, et comme elles peuvent être utiles en pratique, nous aurons soin d'en donner les moyennes dans nos conclusions.

Les tableaux nos XVII et XVIII font voir que les mêmes règles s'appliquent également aux pièces soumises à la flexion. Les flèches permanentes sont comprises dans la colonne des flèches totales corrigées. Pour mieux faire ressortir la proportionnalité entre les flèches et les charges correspondantes, nous avons ramené toutes les expériences à une charge constante de 100 kilogrammes. Et, en effet, les flèches ainsi trouvées par le calcul s'accordent suffisamment pour qu'on ait pu se servir de leurs moyennes pour calculer le coefficient d'élasticité.

II. Les tringles que nous avons prises dans une même couche, mais dans des parties de l'arbre exposées aux quatre points cardinaux (tableau n° VIII), n'ont présenté aucune régularité dans les différences de leurs propriétés mécaniques. En effet, pour différentes couches annuelles d'une même bille, les maxima et les minima se sont trouvés tantôt dans l'une, tantôt dans l'autre de ces directions.. Et cette irrégularité a été tellement constante dans tous les cas, qu'après avoir examiné quatorze billes différentes de chêne, hêtre, acacia, sapin et pin, nous avons cru inutile de pousser plus loin cette recherche. Aussi, lorsqu'il s'est agi de déterminer la marche des propriétés mécaniques dans les couches de ces billes, nous nous sommes servis des moyennes des quatre valeurs ainsi trouvées pour chaque couche.

Pour deux de ces billes, chêne et hêtre, nous avons non-seulement soumis à des expériences d'allongement des tringles provenant des mêmes couches annuelles, mais encore contrôlé nos résultats par la méthode de la flexion sur des cylindres d'un assez fort diamètre pris dans les expositions intermédiaires, *Pl. I, fig.* 2, c'est-à-dire dans les parties exposées au nord-est, nord-ouest, sud-est et sud-ouest.

Les résultats de ces dernières expériences, portés au tableau n° XIV, confirment en tout point ceux obtenus par l'allongement.

III. Nous avons réuni dans le tableau n° IX tous les résultats des expériences sur l'influence de l'humidité. Toutes les tringles sur lesquelles nous avons opéré ont été examinées dans trois ou quatre états différents, et le tableau présente les couches auxquelles elles appartenaient classées d'après leur distance au centre, et d'après leur degré d'humidité. Nous devons toutefois faire remarquer qu'ainsi que nous l'avons déjà dit précédemment, les mêmes tringles n'ont pas pu être employées dans tous les degrés d'humidité, et que, pour avoir des points de comparaison assez nombreux, nous avons été obligés de considérer comme identiques des tringles prises dans les mêmes couches et immédiatement l'une à côté de l'autre. Cette identité peut toutefois ne pas avoir été toujours complète, et cette circonstance explique les anomalies qui se rencontrent quelquefois dans le tableau.

La densité diminue, en général, comme on le sait, avec la quantité d'eau contenue. Cette diminution est très-sensible toutes les fois qu'il y a une grande distance entre les degrés d'humidité. Les différences de densité que l'on trouve alors sont assez grandes pour ne pas être masquées par les causes d'erreur et par les irrégularités que nous avons déjà signalées. Aussi nous regrettons d'avoir été obligés de n'opérer que sur des tringles très-minces, afin de pouvoir comparer les couches elles-mêmes. Ces tringles se dessèchent très-vite à l'air, et il en est résulté qu'il n'y avait presque jamais un écart de plus de 10 ou 20 pour 100 entre les tringles les plus sèches et celles les plus humides. Les difficultés de déterminations précises entre des limites si rapprochées, et surtout pour les cas où nous opérions sur de petits morceaux pris aux extrémités de chaque tringle, expliquent les nombreuses anomalies que nous avons rencontrées pour la densité, et principalement dans les couches extérieures des bois résineux. Malgré ces anomalies, la marche générale des chiffres fait voir que, non-seulement la densité diminue par suite de la dessiccation, mais même proportionnellement à celle-ci.

Pour établir cette loi, que nous sommes loin de donner comme rigoureusement exacte, nous avons comparé les densités aux différents degrés de desséchement successifs avec la densité au plus fort degré d'humidité.

Désignons par h la plus grande humidité exprimée en centièmes du poids du bois; par d, la densité correspondante. Soient h' et d' les mêmes quantités pour un moindre degré d'humidité, et, enfin, c le coefficient de variation de densité pour 1 pour 100 d'humidité; on aura

$$d'=d[1-c(h-h')],$$

d'où

$$c = \frac{d - d'}{d(h - h')}.$$

Nous avons trouvé pour une même couche, et pour les différents degrés d'humidité, des valeurs de c assez rapprochées pour que nous ayons pu en prendre la moyenne, en omettant toutefois celles dans lesquelles la différence d'humidité ne dépassait pas 1 pour 100; et nous avons porté au tableau n° X les moyennes ainsi trouvées pour chaque couche, en marquant du signe + les cas exceptionnels, c'est-à-dire ceux dans lesquels la densité avait augmenté au lieu de diminuer. Dans ce cas, la formule donnée plus haut devient

$$d' = d[1 + c(h - h')].$$

Les valeurs de c varient notablement pour les différentes couches. Cependant il nous a paru rationnel d'établir la moyenne de tous les coefficients trouvés pour une même essence, comme chiffre applicable dans les calculs sur des arbres entiers.

La vitesse du son augmente toujours avec la dessiccation, lorsqu'on opère sur les mêmes tringles. On en trouve un exemple dans celles provenant des six billes coupées dans le sapin n° 65 (tableau n° IX), et qui n'offrent pas une seule exception à cette règle. Les exceptions qui se trouvent dans le tableau, pour les autres billes, proviennent presque toutes de ce qu'il y avait deux séries de tringles, et elles disparaissent lorsqu'on a soin de ne comparer entre elles que les tringles d'une même série : c'est-à-dire, pour la première série, celles du bois vert et celles desséchées au soleil; et, pour la seconde, celles desséchées au laboratoire et à l'étuve. Cette augmentation de la vitesse du son est sensiblement proportionnelle à la perte d'eau, et nous en avons déterminé les coefficients, pour une dessiccation de 1 pour 100, par un calcul analogue à celui dont nous nous étions servis pour les coefficients des variations de densité.

Soient v et v' les vitesses du son aux humidités h et h', h étant la plus forte des deux humidités; soit c' le coefficient de variation de la vitesse du son, on aura

$$v' = v[1 + c'(h - h')].$$

Nous avons calculé, au moyen de cette formule, les différentes valeurs de c', que nous avons trouvées, en général, constantes pour une même couche à différents degrés d'humidité. Nous en avons donc, comme pour les densités, pris les moyennes, que nous avons de même portées au tableau n° X, ainsi que les moyennes générales pour une même essence.

Quant à l'influence de l'humidité sur la valeur du coefficient d'élasticité, nous avons déjà rappelé, dans la discussion des méthodes, la formule au moyen de laquelle on déduit ce coefficient de la densité et de la vitesse du son, et nous nous en sommes servis pour calculer, dans chaque cas, les coefficients d'élasticité aux différents degrés d'humidité, portés dans le tableau n° IX.

Cette formule est

$$E = \frac{dv^2}{g}.$$

Donc, étant donné le coefficient d'élasticité E à une humidité h, on trouvera ce même coefficient E', pour une humidité moindre h', au moyen de la formule

$$E' = \frac{dv^2}{g}[1 - c(h - h')][1 + c'(h - h')]^2;$$

et, en faisant $h - h' = H$, on aura

$$E' = E(1 - cH)(1 + c'H)^2,$$

où c et c' sont déjà donnés pour chaque essence par le tableau n° X.

Cette équation donne la marche progressive du coefficient d'élasticité avec la dessiccation.

En général, d'après les valeurs résultant de nos expériences, on a $c' > c$, ou, tout au plus, $c' = c$, ainsi que cela a lieu très-sensiblement pour le frêne. Dans ces cas, le coefficient d'élasticité augmentera constamment avec la valeur de H, c'est-à-dire avec la dessiccation.

En effet, soit $c = c'$, l'équation deviendra

$$E' = E[1 + cH - (cH)^2 - (cH)^3].$$

Or il résulte des valeurs trouvées pour c et c', que la quantité cH sera toujours une fraction, H ne pouvant, par sa nature même, être supérieur à 60 ou 70. Les valeurs de E' croîtront donc constamment avec celles de H; et cela aura lieu à fortiori, lorsqu'on aura $c < c'$.

Mais il n'en est plus de même si on a $c > c'$, cas que nous n'avons rencontré que dans le sapin. La marche du coefficient d'élasticité dépendra alors du rappport entre c et c'. En substituant dans la formule les valeurs de ces deux coefficients, on trouve que E' atteint un maximum pour $H = 23.21$. Mais, avant d'être admise, cette conséquence de la formule aurait besoin d'être vérifiée par des expériences spéciales faites avec des dessiccations lentes, de centième en centième.

Si l'on avait $c = 2c'$, cas qui ne s'est jamais présenté dans les espèces d'arbres sur lesquelles nous opérions, on trouverait

$$E' = E[1 - 3(c'H)^2 - 2(c'H)^3],$$

c'est-à-dire que l'élasticité diminuerait constamment avec la dessiccation.

Enfin, la cohésion ou la résistance à la rupture par traction augmente, dans presque tous les cas (*voir* le tableau n° IX), par suite de la dessiccation, et dans une assez forte proportion. C'est seulement lorsque la dessiccation avait été poussée jusqu'à ne laisser que 10 pour 100 d'humidité qu'il s'est présenté des diminutions de cohésion bien caractérisées. Il serait difficile de décider si elles provenaient d'une altération dans les fibres ou dans leur texture, produite par la chaleur, ou s'il faut les attribuer à ce que les bois très-secs ne prennent presque plus d'allongement permanent; ils deviennent alors tellement peu flexibles et tellement cassants, qu'ils finissent par se rompre sous le moindre choc, ou effort transversal, dans la mise de la charge. Cette circonstance explique aussi l'opinion généralement admise de la plus grande force du bois vert, opinion énoncée par les auteurs qui n'ont soumis les bois qu'à la flexion. Nous n'avons pas cru devoir déterminer les coefficients de l'augmentation généralement observée par nous, parce que, comme nous l'avons déjà fait remarquer, les expériences de rupture offrent trop peu de précision pour permettre un calcul de ce genre.

Indépendamment des propriétés mécaniques que nous avons étudiées dans toutes les parties de notre travail, il nous a paru utile de profiter des dimensions trouvées pour les tringles à différents degrés d'humidité, pour déterminer leur contraction transversale par suite de la dessiccation. A cet effet, nous avons pris, aux mêmes degrés de dessiccation, les moyennes entre les côtés des sections carrées de toutes les tringles appartenant à une même bille. Leurs rapports, dans tous les cas où la marche a été régulière, nous ont donné les coefficients moyens de contraction pour une perte de 1 pour 100 d'humidité. Ces coefficients et les dimensions des côtés dont ils ont été déduits sont compris dans le tableau n° X. Nous avons porté en regard les moyennes pour chaque bille et pour chaque essence. Mais comme nous avons trouvé quelquefois des variations plus grandes pour les différentes billes d'une même essence que pour la plupart des différentes essences entre elles, nous avons pris la moyenne générale entre tous les cas observés; cette moyenne nous paraît devoir être employée comme chiffre pratique, jusqu'à ce que de nouvelles expériences spéciales et plus nombreuses aient été faites.

IV. Les recherches que nous venons de discuter nous ont mis à même de rendre toutes nos expériences comparables, en les ramenant à un même degré de dessiccatio L'humidité de 20 pour 100 nous a paru la plus convenab comme point fixe, puisque c'est celle à laquelle arriven à peu de chose près, les bois par leur dessiccation spon tanée. Pour opérer cette réduction, nous avons calculé l densités et les vitesses du son par interpolation entre l chiffres trouvés aux deux humidités les plus voisines de 2 pour 100, l'une au-dessus, l'autre au-dessous. Lorsque nou n'avions pas d'observation au-dessus de 20 pour 100, nou avons pris celle qui s'en rapprochait le plus, et une second différant de celle-ci de quelques centièmes seulement. Nou avions donc dans chaque cas quatre observations, c'est-à-dire deux densités d et deux vitesses de son v. En substituant ces valeurs dans la formule d'interpolation

$$d = a + bh \quad \text{et} \quad v = a' + b'h,$$

on a déterminé les quatre constantes, ce qui a donné l densité et la vitesse cherchées, en mettant $h = 20$. Nou avons mieux aimé suivre cette marche que de nous servi des coefficients moyens déterminés précédemment d'aprè toutes les expériences. En effet, ayant à rechercher, non plus la marche générale de la dessiccation, mais bien l chiffre spécial applicable à un seul degré d'humidité, nous devions, au lieu des limites les plus éloignées, prendre les observations les plus voisines de ce point fixe.

Les coefficients d'élasticité ont été calculés d'après les valeurs ainsi trouvées pour la densité et la vitesse du son : seulement, comme il était essentiel d'avoir, non les coefficients résultant des vibrations, mais ceux qui se déduisent de l'allongement, et que nous avons appelés réels, nous avons appliqué à ces premiers les coefficients de correction donnés par le tableau n° VII.

Les cohésions ont été calculées de même par interpolation. Lorsque, pour une couche, il n'y avait d'observations qu'à un seul degré d'humidité, on a cherché les coefficients de variation pour les autres couches, de même qu'on l'avait déjà fait pour la densité et pour la vitesse du son, et l'on a adopté pour cette couche la moyenne des coefficients trouvés ainsi pour les autres couches de la même bille; et lorsque, pour toutes les couches, il n'y avait qu'une série d'observations, on s'est servi de la moyenne des coefficients trouvés pour toutes les billes de la même essence. Enfin, lorsque cela ne se pouvait pas, ou que les observations étaient à une trop grande distance de 20 pour 100, on a porté dans le tableau les cohésions correspondantes à l'humidité la plus rapprochée de cette limite.

En parcourant le tableau n° XII, on verra qu'en général la marche des propriétés mécaniques est la même dans les différentes couches d'une même bille. Ainsi la couche la plus dense est ordinairement celle qui conduit le son avec la plus grande vitesse, qui a par conséquent le coefficient d'élasticité le plus élevé, et celle aussi qui présente la plus grande cohésion. Toutefois l'exemple du hêtre n° 41 (1) fait voir que la densité et la vitesse du son vont quelquefois en sens contraire. Pour le plus grand nombre des arbres que nous avons réduits en tringles, cette marche des propriétés mécaniques du centre à la circonférence est précisément l'inverse de celle qu'on avait admise généralement jusqu'ici. En effet, pour le sapin, le pin, le charme, le frêne, l'orme, l'érable, le sycomore, le tremble, l'aune, la densité, la vitesse du son, le coefficient d'élasticité et la cohésion vont d'une manière à très-peu près constante en augmentant du centre à la circonférence. Il arrive cependant quelquefois que, pour les tringles les plus voisines de l'écorce, les chiffres qui expriment ces propriétés redescendent un peu. C'est surtout dans les bois résineux, où un grand nombre d'expériences comparatives ont été faites, que cet accroissement constant est remarquable; il est tel que, dans les gros arbres, le coefficient d'élasticité des couches extérieures est souvent le double, quelquefois même plus du double de celui du cœur même de l'arbre. L'acacia, sans présenter la même régularité, suit, en général, la même marche que les essences précédentes.

Mais il n'en est plus de même pour le chêne et le bouleau. Dans les arbres que nous avons examinés, le maximum des propriétés mécaniques se trouve généralement dans une couche intermédiaire entre le centre et la circonférence, à environ un tiers du rayon à partir du centre. En allant du centre vers la circonférence, les propriétés mécaniques augmentent jusqu'à cette couche, pour ensuite redescendre au-dessous même de leur point de départ.

Pour le hêtre, où nous avons opéré sur deux arbres, l'un de 50, l'autre de 95 ans, les propriétés vont en sens inverse dans chacun de ces deux arbres. Elles augmentent presque régulièrement du centre à la circonférence pour celui de 50 ans, et, pour celui de 95, où la couche du centre nous manquait, elles vont en diminuant pour toutes les autres. Cette influence si marquée de l'âge, que le hêtre nous a permis de constater, doit être prise en considération dans l'appréciation des résultats trouvés pour les autres espèces. En effet, les deux chênes que nous avons examinés avaient 95 et 164 ans, le bouleau 114; les autres arbres, de 26 à 61 ans, excepté un gros sapin de 110 ans. Ne faut-il pas en conclure que, pour les arbres à aubier, c'est-à-dire ceux dont les couches les plus anciennes s'oblitèrent avec l'âge pour former ce qu'on appelle le bois de cœur, tels que le chêne, le hêtre, etc., il y a une certaine époque de la vie où la modification introduite par l'âge dans l'état relatif de leurs couches amène une inversion dans la marche des propriétés mécaniques; tandis que pour les essences dont toutes les couches restent perméables aux liquides, telles que les bois résineux et la plupart des bois blancs, ces propriétés vont toujours en croissant du centre à la circonférence, quel que soit l'âge des arbres?

Nous n'avons pas fait entrer dans les considérations précédentes les résultats concernant le peuplier, parce que l'arbre dont nous nous sommes servis était malade à la base.

Pour embrasser d'un coup d'œil la marche de chacune de ces propriétés dans les couches successives de chaque bille, on peut reproduire graphiquement les résultats de nos expériences. En prenant les couches annuelles pour abscisses, et leurs densités, vitesses du son, coefficients d'élasticité ou cohésions pour ordonnées, on obtient des courbes correspondant à chacune de ces propriétés et donnant leur marche relative dans chaque bille, ou la marche relative de l'une de ces propriétés dans des billes différentes.

V. La recherche des différences que les propriétés mécaniques présentent suivant la hauteur dans l'arbre est une des questions les plus importantes que nous avions à traiter, soit qu'on les considère dans le sens des fibres, pour une seule couche ou pour la masse entière de l'arbre, soit qu'on les étudie dans des directions perpendiculaires à celle-ci. Tous les résultats qui ont rapport à cette question sont réunis dans le tableau n° XVI; mais ce tableau n'étant lui-même qu'un résumé de ceux qui le précèdent, ce n'est qu'après avoir expliqué comment ceux-ci ont été établis, que nous pourrons en aborder la discussion.

Nous avons déjà vu que le tableau n° XII donne les valeurs des densités, coefficients d'élasticité et cohésions pour chaque couche, ramenés à 20 pour 100 d'humidité; mais il fallait déduire des valeurs trouvées pour chacune les chiffres moyens applicables à la bille entière, afin de pouvoir, non-seulement comparer la méthode de l'allongement à celle de la flexion, mais encore toutes les billes d'un même arbre entre elles, qu'elles aient été disséquées ou non. Pour cela, nous avons mesuré (*voir* le tableau n° XIII) les rayons des billes et les épaisseurs des anneaux successifs au milieu desquels les tringles avaient été prises, et, en admettant que les propriétés de chaque tringle s'appliquent à toutes les couches voisines qui composent le même anneau, nous n'avions qu'à multiplier la densité, le coefficient d'élasticité et la cohésion de chaque anneau par son aire, à faire la somme de ces produits, et à la diviser par la section de la bille entière pour avoir les moyennes cherchées. Ces moyennes sont portées dans les trois dernières colonnes du tableau n° XII. Nous n'avons pas pu faire de calcul analogue pour la vitesse du son, parce que ce serait un problème à part que de la déterminer pour un cylindre composé de couches concentriques douées de vitesses du son différentes.

Le tableau n° XIV contient les données et les résultats de toutes les expériences faites par la flexion sur les billes, le degré d'humidité de celles-ci, les densités et les coefficients d'élasticité trouvés par les expériences, et leurs valeurs ramenées à 20 pour 100 d'humidité, au moyen des coefficients précédemment calculés. Parmi ces billes, il y en a plusieurs qui proviennent d'un même arbre à différentes hauteurs, et qui ont dû, par conséquent, être comprises dans le tableau n° XVI.

Le tableau n° XV contient de même les données et les résultats des expériences faites, au moyen des vibrations transversales et de la rupture par traction, sur les barreaux pris perpendiculairement à la direction des fibres, à la hauteur des différentes billes, dans le sens du rayon et dans celui de la tangente aux couches annuelles.

Enfin, on trouve dans le tableau n° XVI :

(*a*). Les valeurs des propriétés mécaniques dans le sens des fibres pour une même couche ligneuse à différentes hauteurs. Afin de pouvoir faire cette recherche, nous avions, dans la dissection, pris les tringles dans les mêmes couches des différentes billes appartenant au même arbre, ce qui a été facile, en les comptant à partir de la circonférence. Ces tringles correspondantes sont désignées, non par les chiffres contenus dans les tableaux précédents, mais par les lettres *a*, *b*, *c*, *d*; *a* étant la tringle la plus voisine de l'écorce.

(*b*). Les propriétés mécaniques des billes entières, soit qu'elles aient été obtenues directement par la flexion, soit qu'elles aient été déduites de l'allongement des tringles. Les billes sont rangées d'après leur hauteur dans l'arbre, à partir de la base.

(*c*). Les propriétés mécaniques dans le sens du rayon, à différentes hauteurs.

(*d*). Ces mêmes propriétés dans le sens de la tangente aux couches ligneuses.

Les chiffres contenus dans ce tableau font voir qu'en général les propriétés mécaniques diminuent avec la hauteur dans un même arbre pour toutes les couches annuelles examinées séparément dans le sens des fibres. Cette diminution est assez considérable, et on la retrouve également dans les barreaux pris dans les deux directions perpendiculaires à l'axe de l'arbre; mais, lorsqu'on compare entre elles, dans le sens des fibres, les billes entières coupées à différentes hauteurs, on n'obtient plus cette marche régulière, ce qui, du reste, aurait pu se prévoir à priori. En effet, nous avons vu que, pour certains arbres, les propriétés mécaniques sont les plus faibles dans les couches extérieures; d'un autre côté, elles vont également en diminuant de la base vers la cime pour chaque couche : et puisque ce sont seulement les couches extérieures qui se continuent jusqu'en haut, il est évident que la partie supérieure de la tige formée par leur ensemble devra, pour ces arbres, être douée de propriétés inférieures à celles de la base. C'est aussi ce qui a lieu pour le chêne n° 34. Mais il n'en est plus de même pour les arbres dont les couches extérieures sont les plus fortes. Dans ceux-ci, le rapport entre les valeurs des propriétés des billes prises à la base et de celles prises au sommet, dépendra du rapport entre la loi d'accroissement dans les différentes couches du centre à la circonférence, et la loi de décroissement dans une même couche de la base au sommet. Il pourra donc y avoir, pour ces arbres, augmentation, constance ou diminution, et c'est, en effet, ce qui a lieu. Toutefois, dans les expériences que nous avons faites, les cas de diminution ont été les plus nombreux.

VI. Nous venons de faire voir comment l'élasticité varie avec la hauteur, non-seulement dans le sens de l'axe de l'arbre, mais aussi suivant le rayon et la tangente. Il est bien entendu que nous sommes loin de considérer aucune de ces lignes comme de véritables axes d'élasticité; car, pour que cette désignation leur fût applicable, il faudrait que l'élasticité restât la même, non-seulement dans toute la longueur de chacune d'elles, mais encore dans toutes leurs parallèles. Or rien de pareil n'a lieu dans le bois : l'élasticité varie avec la hauteur; elle varie de couche en couche, et enfin dans une même diamétrale suivant la distance du barreau au centre : c'est ce que démontre l'exemple du barreau R pris à la base du pin n° 31 (*voir* tableau n° XV). Ce barreau, après avoir été examiné en entier, a été coupé en deux parties égales, dont l'une, *a*, allait du centre de l'arbre à la moitié du rayon, et l'autre, *b*, de ce point à la circonférence. Le coefficient d'élasticité de cette dernière partie a été trouvé plus élevé que celui de la première, ce qui est bien d'accord avec la marche de l'élasticité dans les couches de cet arbre. On conçoit que l'on doit rencontrer des différences du même ordre selon que l'on prend un barreau tangentiel plus ou moins près de la circonférence. Nous n'en avons pas moins recherché les rapports des élasticités et des cohésions dans ces trois sens, à cause de l'importance pratique de ces données.

Ces rapports (tableau n° XVI) restent sensiblement les mêmes à différentes hauteurs dans un même arbre; mais ils varient avec les espèces. Lorsqu'on prend pour unités l'élasticité et la cohésion moyenne dans le sens des fibres, on trouve en moyenne générale, pour les coefficients d'élasticité dans le sens du rayon et de la tangente, les nombres 0,165 et 0,091 ; et pour les cohésions suivant ces deux directions, 0,163 et 0,159.

VII à X. Nous avons déjà dit, en parlant du choix des arbres, que nous avions pris différentes séries de chênes, de hêtres, de sapins et de pins, au moyen desquelles nous espérions arriver à reconnaître l'influence qu'exercent sur les propriétés mécaniques des arbres, l'âge, l'épaisseur des couches, l'exposition, la nature du terrain et l'époque de l'abatage. Dans la discussion des méthodes, nous avons fait connaître les difficultés qui se sont présentées pour l'application des formules connues aux flèches données par la flexion des billes des bois résineux, et qui ne nous permettent pas de rien conclure, quant à présent, de cette partie de nos expériences; mais nous avons pu remplacer, en partie au moins, la série des billes de sapin par les pièces de cette essence qui ont été équarries dans les dimensions de la pratique, et avoir ainsi quelques résultats comparatifs pour les bois résineux.

Le tableau n° XIX contient :

1°. Les valeurs trouvées pour les densités et les coefficients d'élasticité des billes de chêne et de hêtre, et ramenées à 20 pour 100 d'humidité : ces chiffres sont classés d'après l'âge des arbres et leur provenance, de manière à rendre la discussion plus facile ;

2°. Les valeurs des densités, coefficients d'élasticité et cohésions des pièces équarries de sapin, classées de même d'après leur provenance et leur grosseur. Nous manquions ici de deux données : le degré d'humidité, qui n'a pas été déterminé pour ces pièces, et l'âge des arbres. Mais on peut admettre que l'âge était sensiblement proportionnel à la grosseur, et que le degré d'humidité se rapprochait de 20 pour 100, ces pièces ayant un an de coupe.

Ce tableau fait voir que, dans la limite de nos expériences au moins, la densité a été complétement indépendante des influences que nous recherchions, et que ses variations pour des arbres de même essence sont peu importantes. Elle ne présente de différences un peu fortes que pour le sapin : ce qu'il faut attribuer à ce que ces valeurs ne sont point ramenées à un degré constant d'humidité.

Il n'en est pas de même du coefficient d'élasticité, qui paraît diminuer à mesure que l'âge des arbres augmente. Cette diminution a été constante pour les chênes pris dans des circonstances comparables. Elle a lieu aussi pour le sapin et pour le hêtre, quoique d'une manière moins évidente pour cette dernière essence.

Le plus ou moins de sécheresse, et l'exposition du terrain dans lequel les arbres ont poussé, paraissent aussi réagir sur la valeur du coefficient d'élasticité. Ainsi les bois venus aux expositions nord, nord-est, nord-ouest, et dans les terrains secs, ont toujours un coefficient élevé, et d'autant plus fort que ces deux conditions se trouvent réunies; tandis que les arbres venus dans des terrains fangeux présentent, à quelques exceptions près, les coefficients les plus faibles. C'est surtout sur le hêtre que l'effet de ces circonstances est le plus marqué.

L'âge et l'exposition influent sur la cohésion des pièces de sapin comme sur leur élasticité, et dans le même sens; ce qui fait voir que, sous ce rapport, comme sous beaucoup d'autres, la marche de la cohésion s'accorde avec celle de l'élasticité.

Les coefficients d'élasticité des hêtres venus dans le grès vosgien sont tous plus forts, pour des arbres comparables, que ceux des hêtres venus dans le grès bigarré et dans le muschelkalk. Nous n'avons rien trouvé de semblable pour le chêne, et l'on sait que nous n'avons eu à notre disposition que des sapins du grès vosgien. Il serait difficile de tirer une conclusion générale de l'exemple du hêtre seul, quelque constants et quelque marqués qu'aient été les résultats. En effet, on a déjà vu combien la sécheresse du sol influe sur l'élasticité de cet arbre; il serait donc possible que la grande perméabilité des couches supérieures du grès vosgien, qui ne leur permet pas de retenir longtemps les eaux pluviales, soit en partie cause de la plus grande élasticité des hêtres venus dans les terrains de cette formation.

Les arbres qui avaient été coupés en pleine séve, et dont les uns avaient été écorcés et exposés au soleil, les autres non écorcés et conduits immédiatement sous le hangar où étaient réunies les billes coupées avant la séve, ne nous ont rien présenté de particulier. Mais, comme nous n'avons pris qu'un petit nombre d'arbres dans ces conditions, il faudrait de nouvelles expériences spéciales et nombreuses pour déterminer l'influence de l'abatage en séve. Nous pouvons toutefois conclure des nôtres que le coefficient d'élasticité des bois n'est pas sensiblement modifié par l'époque de leur abatage. Il n'en est probablement pas de même quant à leur conservation; mais cette question est complétement en dehors de celles que nous avions à étudier dans ce travail.

Nous avions enfin à rechercher l'influence de l'épaisseur des couches ligneuses sur les propriétés mécaniques des bois. Nous l'avons fait en déterminant l'épaisseur moyenne des couches de chaque bille, et nous avons trouvé qu'elle variait d'une manière tout à fait indépendante de la marche de ces propriétés. Mais, comme il était possible que cela fût dû à la position relative et à l'alternance des couches minces, et des couches plus épaisses qui se trouvent dans presque tous les arbres, nous avons cherché ensuite ce qui avait lieu pour les tringles qui ne comprenaient que des couches de même épaisseur et en petit nombre. Le sapin seul nous a présenté une relation entre l'épaisseur des couches et leur élasticité; celle-ci est d'autant plus forte que les couches sont plus minces, et la marche de cet amincissement est ordinairement la même que celle de l'augmentation du coefficient d'élasticité dans l'arbre. Cependant, pour des couches de même largeur à différentes distances du centre, l'élasticité est toujours plus forte dans celles qui en sont le plus éloignées. L'amincissement des couches n'est donc pas la cause première de cette augmentation d'élasticité qu'on trouve dans les sapins, en allant du centre à la circonférence.

D'après ce qui précède, il y a lieu de croire que la qualité supérieure des pins du Nord ne doit pas être attribuée exclusivement au peu d'épaisseur de leurs couches ligneuses, et qu'elle provient en grande partie du climat et du terrain dans lequel ils ont végété.

XI. Nous avons déjà fait remarquer que, dans un même arbre et au même degré d'humidité, les propriétés marchent, en général, dans le même sens. Ainsi, la couche qui, à une certaine hauteur, présente la plus grande densité, est douée ordinairement aussi de la plus grande élasticité et de la plus forte cohésion. Ce résultat trouvé sur les tringles a été confirmé, quant au rapport entre la densité et la cohésion, par des expériences spéciales faites sur six sapins, dont trois avaient été débités en planches, et les autres en madriers. Les *fig.* 1 à 6 de la *Pl. II* donnent les positions relatives de ces pièces dans les arbres, leurs dimensions, leurs poids absolus Π et les charges P qui ont produit la rupture d'après la méthode et avec l'appareil précédemment décrits pour des pièces de ce genre.

Ce rapport des différentes propriétés mécaniques entre elles, trop irrégulier déjà dans un même arbre, et trop peu constant pour pouvoir être exprimé par une formule, ne se retrouve, lorsqu'on compare entre eux des arbres de la même essence, qu'entre l'élasticité et la cohésion; il disparaît complétement lorsqu'on établit cette comparaison entre les chiffres moyens trouvés pour les différentes espèces d'arbres. Il est vrai que le pin et le peuplier, dont la densité est très-faible, offrent les coefficients d'élasticité, les limites d'élasticité et les cohésions les plus faibles; mais, d'un autre côté, le sapin, qui est de même très-peu dense, a un coefficient d'élasticité très-élevé; le charme et le hêtre, qui ont un grand poids spécifique, n'ont, au contraire, qu'une faible cohésion; et enfin l'acacia, supérieur à toutes les essences quant à l'élasticité et à la cohésion, a une densité inférieure à celle de plusieurs d'entre elles.

XII. Avant de donner les chiffres moyens résultant de toutes nos expériences, et que nous considérons comme les plus propres aux applications pratiques, nous devons revenir sur la limite d'élasticité et l'allongement permanent maximum dont nous n'avons parlé jusqu'à présent que pour faire remarquer qu'il est impossible d'en déterminer les valeurs d'une manière précise, et que les résultats doivent évidemment différer suivant l'exactitude des instruments employés et la manière d'opérer.

Nous avons pris pour expression de la limite d'élasticité le poids en kilogrammes par millimètre carré de section, qui, après avoir agi pendant un assez court espace de temps, produit par extension un allongement permanent proportionnel de 0,00005. Nous avons choisi cette limite, afin que nos chiffres pussent être comparables avec ceux donnés par d'autres auteurs. On aurait évidemment trouvé des limites de beaucoup inférieures en s'arrêtant aux premiers allongements permanents mesurables.

Les chiffres suivants feront voir l'influence du degré d'humidité sur la valeur de cette limite:

Limites d'élasticité.

ESPÈCE.	BOIS VERT.	BOIS DESSÉCHÉ	
		dans un local clos.	à l'air et au soleil.
Acacia	"	3,175	3,188
Sapin	"	1,597	2,153
Charme	1,282	"	"
Bouleau	0,761	"	1,617
Hêtre	"	2,018	2,317
Chêne à glands sessiles	"	1,936	2,349
Pin sylvestre	"	1,391	1,633
Orme	0,987	"	1,842
Sycomore	1,647	"	2,303
Frêne	1,726	"	2,029
Aune	1,449	"	1,809
Tremble	2,302	"	3,082
Érable	"	"	2,715
Peuplier	"	1,200	1,484

On voit que cette valeur s'élève avec la dessiccation : ce qui explique pourquoi les bois très-humides prennent, plus facilement que les bois secs, des courbures permanentes.

Dans les bois fortement desséchés à l'étuve, la limite d'élasticité coïncide presque avec la charge qui produit la rupture, c'est-à-dire que, dans ce cas, les bois ne peuvent presque plus prendre d'allongements permanents.

L'allongement maximum se compose de deux parties : l'une élastique, facile à calculer, dans chaque cas, d'après le coefficient d'élasticité et d'après la charge qui produit la rupture ; l'autre, permanente, qui est très-petite pour les bois. Nous avons trouvé que, dans le bois vert, cette dernière est tout au plus de 0,0007, et, dans le bois desséché, de 0,00032. Il était donc inutile de la donner séparément pour chaque essence. On remarquera seulement qu'elle diminue avec la dessiccation, c'est-à-dire que, plus les bois sont secs, moins ils peuvent s'allonger.

Voici maintenant les données pratiques résultant de notre travail :

ESPÈCE.	DENSITÉ.	du son.	CIENT d'élasticité.	déduit des vibrations et celui trouvé par allongement.	d'élasticité.	COHÉSION.	Coefficient de la contraction transversale.	Coefficients de variation de la densité.	Coefficients de variation de la vitesse du son.
Acacia	0,717	14,19	1261,9	1,193	3,188	7,93	0,00300	0,00555	0,00576
Sapin	0,493	13,96	1113,2	1,056	2,153	4,18(*)	0,00467	0,01026	0,00798
Charme	0,756	11,80	1085,7	1,105	1,282	2,99	0,00149	0,00743	0,00951
Bouleau	0,812	13,32	997,2	1,212	1,617	4,30	0,00347	0,00422	0,00943
Hêtre	0,823	10,06	980,4	1,087	2,317	3,57	0,00412	0,00486	0,01068
Chêne à glands pédonculés	0,808	"	977,8	"	"	6,49	"	"	"
Chêne à glands sessiles	0,872	11,58	921,3	1,117	2,349	5,66	0,00461	0,00427	0,00805
Pin sylvestre	0,559	10,00	564,1	1,086	1,633	2,48	0,01093	0,01056	0,01369

Moyennes résultant des expériences faites dans le sens des fibres sur un seul arbre pour chaque espèce, et ramenées à 20 pour 100 d'humidité.

Orme	0,723	12,40	1165,3	1,175	1,842	6,99	0,00294	0,00386	0,01006
Sycomore	0,692	13,43	1163,8	1,139	2,303	6,16	0,00312	0,00423	0,00540
Frêne	0,697	14,05	1121,4	1,246	2,029	6,78	0,00121	0,00501	0,00489
Aune	0,601	13,95	1108,1	1,121	1,809	4,54	0,00280	0,00410	0,00897
Tremble	0,602	15,30	1075,9	1,035	3,082	7,20	0,00385	0,00230	0,00803
Érable	0,674	12,36	1021,4	1,068	2,715	3,58	0,00328	0,00363	0,00929
Peuplier	0,477	12,89	517,2	1,007	1,484	1,97	0,00583	0,00450	0,00592

NOTA — Les vitesses du son données ici sont les moyennes des vitesses trouvées directement sur les tringles, tandis que les coefficients d'élasticité sont déduits de l'ensemble de nos expériences ; ce ne sont donc pas des valeurs correspondantes.

(*) Le chiffre 4,18 donné pour la cohésion du sapin ne comprend pas les résultats des expériences spéciales aux madriers et aux planches, dans lesquelles les flèches n'avaient pas été mesurées ; en leur appliquant la formule approximative $R = \left(P + \frac{\Pi}{2}\right)\frac{3a}{bc^2}$, on trouve, en moyenne, pour la cohésion des madriers, 5,88, et, pour celle des planches, 6,50.

Expériences faites dans le sens du rayon et dans celui de la tangente.

ESPÈCE.	DANS LE SENS DU RAYON.			DANS LE SENS DE LA TANGENTE.		
	COEFFICIENT d'élasticité.	VITESSE du son.	COHÉSION.	COEFFICIENT d'élasticité.	VITESSE du son.	COHÉSION.
Charme......	208,4	5,14	1,007	103,4	3,60	0,608
Tremble......	107,6	4,86	0,171	43,7	2,74	0,414
Aune........	98,3	4,12	0,329	59,4	3,14	0,175
Sycomore....	134,9	4,51	0,522	80,5	3,42	0,610
Érable.......	157,1	4,63	0,716	72,7	3,12	0,371
Chêne.......	188,7	4,62	0,582	129,8	3,88	0,406
Bouleau......	81,1	3,23	0,823	155,2	4,57	1,063
Hêtre........	269,7	5,53	0,885	159,3	4,26	0,752
Frêne...	111,3	4,19	0,218	102,0	3,80	0,408
Orme........	122,6	4,28	0,345	63,4	3,05	0,366
Peuplier.....	73,3	4,22	0,146	38,9	3,16	0,214
Acacia.......	170,3	4,44	"	152,2	4,07	1,231
Sapin........	94,5	4,02	0,220	34,1	2,36	0,297
Pin sylvestre..	97,7	4,23	0,256	28,6	2,39	0,196

11 à 12........	1	13,00 m	14,00	28,99	32,41	697,00	0,530	1136,7	6404	
9 à 10........	1	11,00	13,00	25,46	28,35	475,00	0,506	1156,7	5394	
8 à 9......	3	9,00	10,48	22,30	24,30	310,75	0,548	1026,9	3447	
6 à 7......	3	9,00	10,46	16,99	19,63	183,50	0,525	1245,0	2082	
Chevron......	3	9,00	10,47	9,27	12,31	57,48	0,481	1257,6	517	
Madrier......	15	3,02	4,24	24,63	5,40	27,79	0,493	1089,8	917	
Planche........	42	3,02	4,25	24,13	2,78	13,74	0,479	1202,2	264	
Expériences sur les pièces, madriers et planches de chêne.										
8½ à 9½......	1	5,50	5,87	23,18	25,28	346,70	1,008	825,1	7889	Chêne à glands sessiles.
8 à 9........	1	5,50	6,11	21,67	23,67	300,30	0,958	822,3	7189	
7 à 8........	1	5,50	7,06	19,07	22,00	273,20	0,922	858,9	5225	
6 à 7........	1	5,50	6,82	15,99	18,90	191,30	0,928	1007,0	5525	
5 à 6........	1	5,50	6,54	13,67	16,10	141,70	0,985	638,1	2225	
Chevron......	1	3,00	4,01	8,28	8,14	17,20	0,636	601,3	540	Chêne à glands pédonculés.
Chevron......	1	2,50	4,00	7,82	8,04	19,10	0,759	774,3	735	
Doublette.....	1	5,50	6,50	29,34	5,46	71,30	0,685	965,8	435	
Échantillon...	1	3,00	3,65	14,34	4,22	18,20	0,824	1210,7	375	
Entrevous....	1	3,00	3,37	24,22	2,82	16,40	0,712	1251,2	335	

Il n'est pas toujours possible de conclure à priori, des chiffres que nous venons de donner, quel sera le meilleur emploi des bois dans la pratique. En effet, cet emploi dépend souvent, en outre, de leur roideur, de leur résistance à la compression et à la torsion, de leur dureté, de leur structure, etc., et surtout de leur durée. Nous devons rappeler aussi que, nos expériences n'ayant porté que sur des arbres venus dans les Vosges, c'est seulement à des bois de cette provenance que nos résultats sont rigoureusement applicables.

L'acacia est l'espèce qui est douée des qualités les plus éminentes sous tous les rapports; il réunit la plus forte cohésion, le coefficient et la limite d'élasticité les plus élevés à une grande dureté et à une longue durée. Ce bois, d'un usage très-restreint jusqu'à présent, pourrait donc être employé très-utilement dans beaucoup de cas, et offrir une ressource précieuse pour les traverses des chemins de fer, surtout à cause de son rapide accroissement et de la facilité avec laquelle il vient dans la plupart des terrains. Il pourrait, en effet, être cultivé sur les berges et dans les terrains vagues de ces chemins, sur les lieux mêmes où il serait utilisé plus tard.

Le sapin distique se range après l'acacia quant à la grandeur du coefficient d'élasticité, et sa cohésion, quoique inférieure à celle de plusieurs autres essences, est cependant assez forte pour que son emploi soit très-avantageux toutes les fois qu'il s'agira d'obtenir une grande résistance élastique avec une pièce d'un poids relativement petit. Son peu d'élasticité et de cohésion dans le sens du rayon et celui de la tangente le rendent, au contraire, moins propre à résister à l'arrachement et à la compression transversale. Du reste, comme les plus fortes couches ligneuses des sapins sont voisines de la circonférence, il faudrait employer autant que possible ces arbres dans leur forme naturelle, au lieu de les équarrir, ainsi qu'on le fait ordinairement. Par la même raison, lorsqu'on les débite en planches et en madriers, les pièces les plus voisines de la circonférence sont aussi les meilleures; et lorsqu'on aura à employer des bois refendus par le milieu, il sera préférable de les placer de manière à ce que le plus grand effort s'exerce sur la partie extérieure.

Le chêne offre cette particularité, que, sans présenter le chiffre le plus élevé pour aucune des propriétés mécaniques, il les réunit cependant toutes à un degré fort remarquable. Cet ensemble de qualités le rend également propre à presque tous les emplois, et explique le rôle important qu'il joue dans la pratique. La préférence qu'on donne au bois de cœur sur l'aubier, et au bois du pied de l'arbre sur celui de la cime, est parfaitement motivée pour le chêne, puisque c'est dans ces parties que les propriétés mécaniques atteignent leur maximum. Ajoutons que, d'après nos expériences, le bois provenant d'un jeune arbre est, à grosseur égale, plus fort que celui d'un arbre plus âgé, et que le chêne à glands pédonculés est de même plus fort que le chêne à glands sessiles.

Le charme, le hêtre et le bouleau ont des coefficients d'élasticité un peu supérieurs ou égaux à ceux des deux variétés de chêne; mais leur cohésion est beaucoup plus faible, et il en est de même de leur limite d'élasticité, le hêtre excepté. Ces arbres sont surtout remarquables par leur grande élasticité et leur grande cohésion dans les deux directions perpendiculaires aux fibres. Sous ce rapport, ils pourraient être d'un très-bon emploi dans les chemins de fer, pourvu que l'on arrive à assurer leur conservation sans altérer leurs propriétés mécaniques. Cette force dans les directions transversales est aussi ce qui les rend propres à donner de très-bonnes dents de roue, et l'ordre suivant lequel les praticiens les rangent à cet égard s'accorde avec les valeurs de leur cohésion dans le sens du rayon.

Le pin sylvestre nous a donné des chiffres plus faibles que toutes les autres essences, à l'exception du peuplier. Cette infériorité nous a d'autant plus surpris, qu'en ce qui concerne l'élasticité au moins, le pin est, en général, considéré comme analogue et quelquefois même supérieur au sapin. Mais avant d'admettre ces chiffres comme la véritable expression des propriétés mécaniques des pins des Vosges, il serait nécessaire de pouvoir faire de nouvelles expériences sur des arbres de cette espèce venus en massifs. Nous n'avons trouvé, en effet, dans les forêts dont nous avons tiré nos arbres, que des sujets isolés dont l'accroissement avait été fort rapide, et l'administration forestière n'a pas cru devoir nous accorder un arbre venu dans les belles futaies de pins qui se trouvaient dans notre voisinage, ce qui nous aurait permis de faire cette expérience comparative.

Pour les autres espèces, nous n'avons examiné qu'un arbre de chacune, et encore n'avons-nous pu, dans quelques cas, nous les procurer que d'un âge ou d'un diamètre peu élevé : aussi nous bornons-nous à donner les chiffres auxquels nous sommes arrivés, sans vouloir nous en servir pour motiver des considérations pratiques, et d'autant plus que quelques-uns des résultats, la cohésion du tremble par exemple, sont en opposition avec les opinions reçues sur la valeur relative de ces espèces. Abstraction faite de ce chiffre pour le tremble, on peut ranger ces essences dans l'ordre suivant, d'après leurs propriétés mécaniques :

Orme.
Frêne.
Sycomore.
Aune.
Tremble.
Érable.
Peuplier.

CINQUIÈME PARTIE.

Conclusions.

De tout ce qui précède, nous croyons pouvoir tirer les conclusions suivantes :

1°. Les valeurs des coefficients d'élasticité et des vitesses du son, déduites des vibrations, sont supérieures aux chiffres que l'on trouve au moyen de l'allongement. Les rapports des nombres donnés par ces deux méthodes sont sensiblement les mêmes pour des arbres de la même espèce, quel que soit leur degré d'humidité; ils servent à trouver le coefficient d'élasticité réel au moyen de la vitesse réelle du son, et réciproquement.

2°. Les allongements produits par l'action de charges dans le sens des fibres se composent d'une partie élastique qui est très-sensiblement proportionnelle aux charges, et d'une partie permanente, mesurable même pour des charges relativement petites, et dont la grandeur varie non-seulement avec la charge, mais encore suivant le temps pendant lequel cette dernière agit.

3°. Cette loi s'applique également aux flèches que prennent même de très-fortes pièces, lorsque, étant posées par leurs extrémités sur deux appuis, on les charge par le milieu de poids successivement croissants.

4°. Les coefficients d'élasticité trouvés par la flexion d'une bille de 2 mètres de longueur s'accordent généralement bien avec les coefficients moyens qui se déduisent des expériences d'allongement sur un grand nombre de tringles provenant de cette bille. Toutefois cet accord n'a pas lieu pour les arbres résineux; les flèches de ceux-ci sont toujours beaucoup plus grandes qu'elles ne devraient l'être d'après l'allongement des tringles.

Lorsque la longueur des pièces est très-considérable par rapport à leur section, les chiffres donnés par la flexion se rapprochent toujours beaucoup de ceux trouvés par allongement, quelle que soit, du reste, la nature de l'arbre.

5°. Des tringles prises dans les mêmes couches annuelles, en différents points, mais à la même hauteur, présentent bien quelques différences dans leurs propriétés mécaniques, mais sans qu'il y ait aucune relation entre les variations observées et la position primitive des tringles dans l'arbre, par rapport aux points cardinaux.

6°. La densité diminue, en général, avec la dessiccation, et proportionnellement à celle-ci. Si l'on désigne par d et d' les densités aux humidités h et h', h étant plus grand que h'; par c, le coefficient de variation de la densité pour une perte d'eau de 1 pour 100, et si l'on met $h - h' = H$, on a

$$d' = d(1 - cH).$$

La vitesse du son augmente avec la dessiccation, et proportionnellement à celle-ci. Soient v et v' les vitesses du son aux humidités h et h', et c' le coefficient de variation de la vitesse du son pour une perte d'eau de 1 pour 100; on aura

$$v' = v(1 + c'H).$$

Le coefficient d'élasticité augmente avec la dessiccation, d'après la formule

$$E' = E(1 - cH)(1 + c'H)^2.$$

Les valeurs relatives de c et c' sont telles pour toutes les espèces que nous avons soumises à l'expérience, que E' croît en même temps que H.

La limite d'élasticité s'élève, et l'allongement maximum diminue avec la dessiccation (nous prenons ici ces deux propriétés dans leur acception usuelle).

La cohésion augmente, dans presque tous les cas, avec les pertes d'eau successives et dans une proportion assez forte; mais cette donnée est, par sa nature même, trop variable pour qu'on puisse soumettre ce résultat au calcul. Lorsque la dessiccation a été poussée artificiellement jusqu'à ne laisser que 10 pour 100 d'eau dans le bois, celui-ci devient tellement cassant, qu'il n'est plus possible de faire des expériences de rupture quelque peu précises.

7°. Les propriétés mécaniques augmentent d'une manière constante, et quelquefois même dans une très-forte proportion, du centre à la circonférence, pour le sapin, quel que soit son âge, pour le pin, le charme, le frêne, l'orme, l'érable, le sycomore, le tremble, l'aune, et en partie pour l'acacia. Cette augmentation paraît être indépendante de l'âge dans les bois résineux, et, en général, dans les espèces dont les couches restent toujours perméables aux liquides. Dans le vieux chêne et le vieux bouleau, les propriétés suivent une marche inverse, c'est-à-dire qu'après avoir augmenté jusqu'au tiers du rayon, elles redescendent ensuite jusqu'à la circonférence. Enfin, dans le hêtre, on trouve la marche ascendante pour un jeune arbre, et la marche décroissante pour un arbre plus âgé, ce qui semblerait indiquer que, dans les arbres dont les couches les plus anciennes s'oblitèrent pour former le bois de cœur, cette transformation modifie la marche des propriétés.

8°. Pour chaque couche annuelle, prise séparément, les propriétés mécaniques diminuent avec la hauteur dans l'arbre; il en est de même dans les directions perpendiculaires à l'axe.

Pour l'ensemble de la tige, il ne peut y avoir que diminution, avec la hauteur, dans les espèces dont les couches les plus faibles sont à la circonférence; et c'est, en effet, ce qui a lieu pour le chêne. Mais, dans les autres espèces, il peut y avoir diminution, constance ou augmentation, selon les rapports entre la loi d'accroissement du centre à la circonférence et la loi de décroissement dans les couches depuis la base jusqu'à la cime.

Toutefois, les cas de diminution avec la hauteur sont, e général, les plus nombreux.

9°. Les rapports entre l'élasticité et la cohésion, dans l sens des fibres, et les mêmes propriétés dans le sens d rayon et de la tangente, ne varient pas sensiblement avec l hauteur dans un même arbre, ni dans des arbres de mêm espèce, mais bien lorsqu'on compare les diverses espèce entre elles.

En moyenne, lorsqu'on prend pour unités les coefficient d'élasticité et les cohésions moyennes dans le sens de l'axe, on trouve, pour les coefficients d'élasticité dans le sens du rayon et de la tangente des arbres, 0,165 et 0,091 ; et pour les cohésions, dans ces deux directions, les nombres 0,163 et 0,159.

10°. On ne remarque aucun rapport régulier entre la densité des arbres et leur âge, l'épaisseur de leurs couches, l'exposition et la nature du terrain.

11°. L'époque de l'abatage des arbres ne paraît pa influer sur leurs propriétés mécaniques.

12°. Le coefficient d'élasticité et la cohésion diminuent mesure que l'âge des arbres augmente.

13°. L'épaisseur relative des couches ne peut être con dérée comme la cause première des différences que l' observe dans un même arbre, ni de celles qui existent en les individus.

Il est vrai que, dans le sapin, l'amincissement graduel couches marche le plus souvent dans le même sens l'augmentation des propriétés du centre à la circonfére mais, dans les cas où le contraire a lieu, cette augment reste néanmoins sensible.

14°. Les bois venus aux expositions nord, nord- nord-ouest, et dans les terrains secs, ont toujou coefficient d'élasticité élevé, et d'autant plus fort q deux conditions se trouvent réunies; tandis que les arbres venus dans les terrains fangeux présentent les coefficients les plus faibles.

C'est surtout pour le hêtre que l'effet de ces influences est le plus marqué.

15°. Les hêtres venus dans le grès vosgien présentent une élasticité supérieure à celle des hêtres venus dans le grès bigarré et dans le muschelkalk.

16°. Dans un même arbre, les diverses propriétés mécaniques marchent presque toujours parallèlement. Ainsi, la couche la plus dense est ordinairement celle qui possède aussi la plus grande vitesse du son, le coefficient d'élasticité le plus élevé, et la plus forte cohésion; mais ce rapport, trop peu constant déjà, dans un même arbre, pour pouvoir être exprimé par une formule, ne se retrouve que rarement lorsqu'on compare entre eux divers arbres d'une même espèce, et il disparaît complétement dans les arbres nature différente.

Tableau n° I. — *Tableau des résultats des expériences*

ESSENCE.	QUALITÉ DU BOIS ET PROVENANCE.	MÉTHODE EMPLOYÉE.	DENSITÉ.	COEFFICIENT d'élasticité.	COHÉSION.	
Chêne.....	"	Extension dans le sens des fibres.	"	"	9,810	Rond
Id........	"	*Id.*	0,845	"	6,466	Barlo
Id........	"	*Id.*	"	"	8,141	Barlo
Id........	"	Flexion.	"	1012	"	Duha
Id........	"	*Id.*	"	1040	"	Aubry
Id........	"	*Id.*	"	969	"	Aubry
Id........	De démolition, 25 ans de coupe.	*Id.*	0,732	1688	"	Dupin
Id........	"	*Id.*	"	1291	"	Ronde
Id........	Anglais.	*Id.*	0,969	614	4,982	Barlow
Id........	Anglais.	*Id.*	0,934	1018	7,053	Barlow
Id........	De Dantzig.	*Id.*	0,756	835	6,296	Barlow
Id........	De l'Adriatique.	*Id.*	0,993	681	5,824	Barlow
Id........	Du Canada.	*Id.*	0,872	1507	7,452	Barlow
Id........	Vieux bois de vaisseau.	*Id.*	0,872	1205	8,350	Ebbels
Id........	Jeune, kings-Langley, Herts	*Id.*	0,863	1151	12,196	Ebbels
Id........	De Beaulieu, Hants.	*Id.*	0,616	740	"	Ebbels
Id........	De Beaulieu, autre pièce.	*Id.*	0,736	617	"	Ebbels
Id........	D'un vieil arbre.	*Id.*	0,625	500	5,516	Ebbels
Id........	De Riga.	*Id.*	0,688	1131	9,033	Ebbels
Id........	Anglais.	*Id.*	0,748	1300	8,982	Ebbels
Id........	Anglais vert.	*Id.*	0,763	911	6,920	Ebbels
Id........	De Dantzig, desséché.	*Id.*	0,755	1405	"	Ebbels
Id........	Quercus sessiliflora.	*Id.*	"	1033	"	Ebbels
Id........	Quercus robur.	*Id.*	"	1158	"	Ebbels
Id........	Nouvellem. abattu, 4 pouces d'équarr., 20 pieds de long.	*Id.*	"	"	6,944	Buffon
Id........	Nouvellem. abattu, 5 pouces d'équarrissage, 28 pieds de long.	*Id.*	"	"	5,391	Buffon
Id........	Nouvellem. abattu, 6 pouces d'équarrissage, 20 pieds de long.	*Id.*	"	"	5,772	Buffon
Id........	Nouvellem. abattu, 7 pouces d'équarrissage, 20 pieds de long.	*Id.*	"	"	6,091	Buffon
Id........	Nouvellem. abattu, 8 pouces d'équarrissage, 20 pieds de long.	*Id.*	"	"	5,574	Buffon
Id........	"	*Id.*	"	"	7,322	Belidor

urs ; sur la densité ; l'élasticité et la cohésion des bois.

QUALITÉ DU BOIS ET PROVENANCE.	MÉTHODE EMPLOYÉE.	DENSITÉ.	COEFFICIENT d'élasticité.	COHÉSION.	AUTEUR.
″	Flexion.	″	″	7,259	Bélidor.
″	*Id.*	″	″	7,124	Bélidor.
″	Extension.	″	1340	″	Minard et Désormes
e de bonne qualité.	*Id.*	″	1178	″	Ardant.
ivant les fibres.	Flexion.	″	1051	″	Hagen.
rpendiculairem. aux fibres	*Id.*	″	71,8	″	Hagen.
″	Extension.	″	1305	″	Paccinotti et Peri.
″	Flexion.	0,712	1505	″	Paccinotti et Peri.
[illegible] ″	Extension.	0,700	″	8,062	Barlow.
an de coupe.	Flexion.	0,659	1110	″	Dupin.
″	*Id.*	0,696	950	6,566	Barlow.
qualité moyenne.	*Id.*	″	″	8,565	Ebbels et Tredgold.
uge, suivant les fibres.	*Id.*	″	1483	″	Hagen.
rpendiculairem. aux fibres	*Id.*	″	66,3	″	Hagen.
anc, suivant les fibres.	*Id.*	″	1467	″	Hagen.
rpendiculairem. aux fibres	*Id.*	″	64,6	″	Hagen.
″	*Id.*	0,618	1068	″	Paccinotti et Peri.
″	Extension.	0,600	″	12,097	Barlow.
″	*Id.*	″	″	11,914	Barlow.
″	Flexion.	0,760	1154	8,548	Barlow.
un jeune arbre.	*Id.*	0,811	″	10,248	Ebbels et Tredgold.
qualité moyenne.	*Id.*	0,690	″	8,033	Ebbels et Tredgold.
″	*Id.*	0,753	″	9,931	Ebbels et Tredgold.
″	*Id.*	0,980	″	13,983	Barlow.
″	*Id.*	0,646	″	6,905	Barlow.
″	*Id.*	0,558	1194	″	Paccinotti et Peri.
Italie.	*Id.*	0,374	″	4,137	Ebbels et Tredgold.
anc.	*Id.*	0,511	″	7,211	Ebbels et Tredgold.
Toscane.	Extension.	″	921	″	Paccinotti et Peri.
e Toscane.	Flexion.	0,534	1106	″	Paccinotti et Peri.
″	*Id.*	0,553	492	4,274	Barlow.
ommun.	*Id.*	0,544	″	6,831	Ebbels et Tredgold.
ert.	*Id.*	0,763	″	6,072	Ebbels et Tredgold.
ert.	*Id.*	0,920	″	6,161	Ebbels et Tredgold.
run.	*Id.*	0,685	1106	″	Ebbels et Tredgold.

[Suite.]

Tableau n° I. — *Tableau des résultats des expériences f*

ESSENCE.	QUALITÉ DU BOIS ET PROVENANCE.	MÉTHODE EMPLOYÉE.	DENSITÉ.	COEFFICIENT d'élasticité.	COHÉSION.	A
Aune......	"	Flexion.	0,555	"	6,705	Ebbels
Platane....	"	*Id.*	0,648	"	7,679	Ebbels
Châtaignier	Vert.	*Id.*	0,875	"	5,693	Ebbels
Id.......	De Toscane.	Extension.	"	1106	"	Paccino
Id.......	De Toscane.	Flexion.	0,508	1175	"	Paccino
Sycomore..	"	*Id.*	0,590	"	6,768	Ebbels
Sorbier....	"	*Id.*	0,673	1201	"	Paccino
Olivier....	"	*Id.*	0,829	836	"	Paccino
Acacia....	Vert.	*Id.*	0,820	"	7,869	Ebbels
Saule......	"	*Id.*	0,405	"	4,618	Ebbels
Bouleau...	"	*Id.*	0,720	"	6,540	Ebbels
Cyprès....	Un an de coupe.	*Id.*	0,664	1372	"	Dupin.
Id......	De Toscane.	*Id.*	0,502	1021	"	Paccino
Arbousier.	"	*Id.*	1,035	1313	"	Paccino
Acajou....	"	Extension.	0,637	"	5,653	Barlow.
Id......	D'Espagne, sec.	*Id.*	0,852	"	5,377	Ebbels
Id.......	De Honduras, sec.	*Id.*	0,560	"	8,059	Ebbels
Id......	"	Flexion.	0,609	1424	"	Paccino
Ébène.....	"	*Id.*	1,125	2091	"	Paccino
Teak......	"	Extension.	0,860	"	10,609	Barlow
Id......	"	Flexion.	0,745	1693	10,386	Barlow
Poon......	"	*Id.*	0,579	"	9,367	Barlow
Mélèze....	"	*Id.*	0,543	702	"	Barlow
Calaba....	"	*Id.*	0,579	1137	"	Barlow
Cèdre.....	Du Liban, sec.	*Id.*	0,486	"	5,212	Ebbels
Sapin.....	"	Extension.	0,600	"	9,039	Barlow
Id......	"	*Id.*	"	"	8,119	Barlow
Id......	De démolit., 25 ans de coupe	Flexion.	0,443	1029	"	Dupin
Id......	"	*Id.*	"	1350	"	Rondel
Id......	Pesse ou de Norwége.	*Id.*	0,660	859	"	Barlow
Id.......	Blanc de Christiania.	*Id.*	0,512	1268	8,678	Ebbels
Id.......	Blanc de Québec.	*Id.*	0,465	875	7,211	Ebbels

sur la densité, l'élasticité et la cohésion des bois.

TÉ DU BOIS ET PROVENANCE.	MÉTHODE EMPLOYÉE.	DENSITÉ.	COEFFICIENT d'élasticité.	COHÉSION.	AUTEUR.
d'Écosse.	Flexion.	0,529	845	7,363	Ebbels et Tredgold.
d'Angleterre.	*Id.*	0,555	977	5,883	Ebbels et Tredgold.
forêt de Mar.	*Id.*	0,696	453	4,828	Barlow.
forêt de Mar.	*Id.*	0,693	611	5,324	Barlow.
forêt de Mar.	*Id.*	0,703	611	5,324	Barlow.
osges.	Extension.	״	1615	״	Ardant.
osges.	*Id.*	״	1188	״	Ardant.
èlement aux fibres.	Flexion.	״	1204	״	Hagen.
ndiculairem. aux fibres	*Id.*	״	25,3	״	Hagen.
״	Extension.	״	1155	״	Paccinotti et Peri.
״	Flexion.	0,484	940	״	Paccinotti et Peri.
abies suivant les fi- s (sapin distique).	*Id.*	״	1330	״	Hagen.
ndiculairem. aux fibres	*Id.*	״	15,7	״	Hagen.
ou d'Écosse.	*Id.*	0,657	1290	5,658	Barlow.
ou de la Nouvelle- gleterre.	*Id.*	0,553	1046	4,650	Barlow.
ord ou de Riga.	*Id.*	0,753	932	4,672	Barlow.
ord ou de Riga.	*Id.*	0,738	696	4,432	Barlow.
érique, de Weymouth.	*Id.*	0,460	״	8,324	Ebbels et Tredgold.
de Riga.	*Id.*	״	1064	״	Ebbels et Tredgold.
de Riga.	*Id.*	0,480	1506	6,705	Ebbels et Tredgold.
de Riga.	*Id.*	0,464	1421	״	Ebbels et Tredgold.
de Long-Sound, Nor- ge.	*Id.*	0,640	1268	7,959	Ebbels et Tredgold.
de Memel.	*Id.*	0,553	1751	6,895	Ebbels et Tredgold.
de Memel.	*Id.*	0,544	1776	״	Ebbels et Tredgold.
.	*Id.*	0,560	740	6,216	Barlow.
.	*Id.*	0,531	433	3,511	Barlow.
.	*Id.*	0,522	631	4,755	Barlow.
.	*Id.*	0,556	740	4,840	Barlow.
, échantillon choisi.	*Id.*	0,640	״	7,995	Ebbels et Tredgold.
, qualité moyenne.	*Id.*	0,622	״	7,047	Ebbels et Tredgold.
, très-jeune.	*Id.*	0,396	״	4,074	Ebbels et Tredgold.
h Pine.)	*Id.*	0,660	861	6,887	Barlow.

Tableau n° II. — *Inventaire des arb*

EXPOSITION.	NUMÉRO de l'arbre.	ESSENCE.	AGE.	FORÊT où l'arbre a été coupé.	QU
Crêtes battues des vents.	26	Chêne à glands sessiles.	60 ans.	Trois-Pierres.	Terrain
Id	24	Sapin.	70 ans.	Trois-Pierres.	Terrain
Id	54	Pin.	33 ans.	Chaume-Martimont.	Terrain
Id	27	Hêtre.	72 ans	Trois-Pierres.	Terrain
Id	25	Bouleau.	68 ans	Trois-Pierres.	Terrain
Pentes arides au sud	48	Chêne à glands sessiles.	51 ans.	Petit-Rougimont.	Terrain
Id	47	Sapin.	52 ans.	Petit-Rougimont.	Terrain
Id	15	Pin.	45 ans.	Chaume du Gros-Rougimont.	Terrain
Id	49	Hêtre.	51 ans.	Petit-Rougimont.	Terrain
Terrains fertiles à l'ouest.	36	Chêne à glands sessiles.	50 ans.	Bergerie.	Terrain
Id	35	Chêne à glands sessiles.	85 ans.	Bergerie.	Terrain
Id	34	Chêne à glands sessiles	95 ans.	Bergerie.	Terrain
Id	37	Chêne à glands sessiles.	105 ans.	Bergerie.	Terrain
Id	43	Chêne à glands sessiles.	164 ans.	Bergerie.	Terrain
Id	19	Sapin.	90 ans.	Gros-Rougimont.	Terrain
Id	18	Sapin.	110 ans.	Gros-Rougimont.	Terrain
Id	17	Sapin.	120 ans.	Gros-Rougimont.	Terrain
Id	16	Sapin.	120 ans.	Gros-Rougimont.	Terrain
Id	14	Pin.	65 ans.	Basse-Joachim.	Terrain
Id	41	Hêtre.	50 ans	Bergerie.	Terrain
Id	38	Hêtre.	51 ans.	Bergerie.	Terrain
Id	42	Hêtre.	60 ans.	Bergerie.	Terrain
Id	32	Hêtre.	90 ans.	Bergerie.	Terrain
Id	46	Hêtre.	95 ans.	Bergerie.	Terrain
Id	39	Bouleau.	114 ans.	Bergerie.	Terrain
Id	40	Charme.	65 ans.	Bergerie.	Terrain
Terrains fertiles au nord, au nord-est et au nord-ouest	30	Chêne à glands sessiles.	103 ans.	Basse Pain-Sec.	Terrain
	65	Sapin.	46 ans.	Mirguet.	Terrain
Id	28	Sapin.	100 ans.	Basse Pain-Sec.	Terrain
Id	50	Pin.	107 ans	Rupt-des-Dames.	Terrain
Id	29	Hêtre.	90 ans.	Basse Pain-Sec.	Terrai
Id	66	Acacia.	23 ans.	Basse Compère.	Terrai
Id	63	Acacia.	23 ans.	Basse Compère.	Terrai
Id	22	Sycomore.	36 ans.	Tête du Gros-Rougimont.	Terrai
Id	23	Erable.	36 ans.	Tête du Gros-Rougimont.	Terrai
Terrains fangeux	52	Chêne à glands sessiles	75 ans.	Rupt-des-Dames.	Terrai
Id	51	Sapin.	140 ans.	Rupt-des-Dames.	Terrai
Id	53	Hêtre.	85 ans.	Petit-Rougimont.	Terrai
Id	13	Pin.	53 ans.	Basse Verdenal.	Terrai

expériences d'allongement et de flexion.

EN.

Arbres coupés hors séve.

CIRCONFÉRENCE moyenne.	HAUTEUR à laquelle a été coupée la bille.	OBSERVATIONS.
m	m	
0,40	0,74	Arbre venu sur souche, dans un taillis peu serré ; d'un accroissement médiocre.
0,68	0,74	Arbre venu dans une clairière semée de bruyères, entre des roches ; d'un accroissement passable.
0,55	0,74	Arbre isolé dans les bruyères, branchu et d'un accroissement passable.
0,65	0,74	Arbre qui avait été dominé dans sa jeunesse, venu dans un taillis, et d'un accroissement passable.
0,50	1,45	Arbre venu dans un taillis peu serré, branchu et d'un accroissement médiocre.
0,50	1,70	Arbre élancé, venu dans un taillis et d'un accroissement passable.
0,42	0,74	Arbre venu entre des roches et dans la bruyère, quoiqu'au milieu d'un taillis ; accroissement passable.
0,82	3,00	Arbre isolé dans les bruyères ; d'un bon accroissement.
0,32	0,74	Arbre élancé, venu dans un taillis ; d'un accroissement médiocre.
0,27	0,74	Arbre crû dans un taillis bien venant, mais qui avait été serré dans sa jeunesse.
0,55	0,74	Arbre crû dans un taillis bien venant ; son accroissement, faible dans sa jeunesse, avait augmenté ensuite, puis diminué de nouveau.
0,82	»	Arbre venu sur souche, dans un taillis bien venant ; d'un bon accroissement, conservé entier.
0,80	0,74	Arbre crû dans un taillis bien venant, mais qui avait été serré dans sa jeunesse ; d'un bon accroissement.
1,10	1,15	Arbre mort en cime, crû dans un taillis bien venant, mais qui avait été serré dans sa jeunesse ; accroissement faible jusqu'à 40 ans, qui augmente ensuite, puis diminue.
0,49	5,50	Arbre venu dans un massif où il avait toujours été dominé ; accroissement médiocre.
0,68	»	Arbre venu en massif, conservé entier.
1,08	11,00	Arbre venu en massif.
1,25	7,50	Arbre venu en massif et d'un bel accroissement.
0,74	5,80	Arbre élancé, crû dans un massif de sapins.
0,40	»	Arbre venu dans une clairière, et d'un bel accroissement ; conservé entier.
0,37	0,10	Arbre crû dans un taillis bien venant, et d'un bel accroissement.
0,33	0,74	Arbre crû dans un taillis serré et bien venant, et qui y avait été dominé.
0,75	0,74	Arbre crû dans un taillis bien venant, très-branchu et d'un bel accroissement.
0,88	1,55	Arbre crû dans un taillis bien venant, et d'un bel accroissement.
1,12	3,00	Arbre élancé, crû dans un taillis bien venant.
0,25	0,15	Arbre crû dans un taillis bien venant, mais très-serré.
0,76	0,74	Arbre élancé, venu dans une clairière, mais qui avait été serré dans sa jeunesse ; accroissement passable.
»	»	Arbre coupé en entier ; venu à l'abri des vents, au bas d'un terrain en pente, et d'un fort bel accroissement.
0,94	3,85	Arbre venu en massif, dominé dans sa jeunesse, et qui avait un chancre profond au milieu de sa longueur.
1,30	1,50	Arbre crû dans la bruyère au milieu d'un taillis ; d'un assez bel accroissement, mais le cimeau rabougri.
0,75	1,50	Arbre crû au milieu d'une sapinière entre des rochers ; accroissement passable.
»	»	Arbre coupé en entier, venu dans un taillis peu serré.
0,36	N° 1. 0,65 N° 2. 3,36	Arbre venu dans un taillis peu serré.
0,42	1,50	Arbre venu sur souche dans un massif de sapinière et d'un bel accroissement.
0,50	3,00	Cet arbre a crû à côté du précédent, et était dans les mêmes conditions.
0,45	0,74	Arbre crû dans un taillis, d'un faible accroissement, et dont les racines baignaient dans l'eau.
0,68	0,74	Arbre d'un faible accroissement, dont les racines baignaient dans l'eau.
0,64	0,74	Arbre crû dans un mauvais taillis, d'un faible accroissement et dont les racines baignaient dans l'eau.
0,63	0,74	Arbre élancé, d'un accroissement passable, crû au milieu de quelques sapins au point de transition des terrains secs et des terrains fangeux.

[Suite.] Tableau n° II. — *Inventaire des arbre*

EXPOSITION.	NUMÉRO de l'arbre.	ESSENCE.	AGE.	FORÊT où l'arbre a été coupé.	
Terrains fertiles à l'ouest	33	Chêne à glands sessiles.	80 ans.	Bergerie.	Te
Id. à l'ouest......	43	Chêne à glands sessiles.	100 ans.	Bergerie.	Te
Id. au nord-ouest.	21	Sapin.	92 ans.	Gros-Rougimont.	Te
Id. au nord-ouest.	20	Sapin.	103 ans.	Gros-Rougimont.	Te
Id. au sud-est....	31	Pin.	58 ans.	Bergerie.	Te
Id. au nord-ouest.	44	Hêtre.	80 ans.	Bergerie.	Te
Terrains secs inclinant légèrement au midi....	3	Chêne à glands pédonculés.	74 ans.	Bois-Canon.	T
Id....................	2	Chêne à glands sessiles.	78 ans.	Bois-Canon.	T
Id....................	1	Hêtre.	72 ans.	Bois-Canon.	T
Terrains fertiles inclinant légèrement au levant...	4	Chêne à glands pédonculés.	78 ans.	Basse Biscuit.	T
Id....	5	Chêne à glands sessiles.	74 ans.	Basse Biscuit.	T
Id....................	6	Hêtre.	60 ans.	Basse Biscuit.	T
Id....................	7	Charme.	61 ans.	Basse Biscuit.	T
Id....................	8	Tremble.	58 ans.	Tranchée de Niderhorff.	T
Terrains fangeux........	9	Chêne à glands pédonculés.	71 ans.	Ruisseau de Fraquelfing.	Te
Id....................	10	Chêne à glands sessiles.	40 ans.	Tranchée de Chasse.	Te
Id.........	11	Hêtre.	67 ans	Ruisseau de Fraquelfing.	Te
Id....................	12	Aune.	38 ans.	Ruisseau de Fraquelfing,	T
Terrasse en terres rapportées, abritée au nord par des constructions..	64	Peuplier.	38 ans.	Verrerie de Cirey.	T
Terrains secs inclinant légèrement au midi....	56	Chêne à glands pédonculés.	73 ans.	Minière.	T
Id	55	Hêtre.	62 ans.	Minière.	T
Terrains fertiles inclinant légèrement au levant..	61	Chêne à glands pédonculés.	74 ans.	Minière.	T
Id	62	Hêtre.	68 ans.	Minière.	T
Terrains fangeux........	59	Chêne à glands pédonculés.	73 ans.	Dringue.	T
Id....................	60	Hêtre.	76 ans.	Dringue.	T
Id....................	57	Frêne.	45 ans.	Dringue.	T
Id....................	58	Orme.	47 ans.	Dringue.	T

ences d'allongement et de flexion.

CIRCONFÉRENCE moyenne.	HAUTEUR à laquelle a été coupée la bille.	OBSERVATIONS.

EN.

Arbres coupés en séve.

CIRCONFÉRENCE moyenne.	HAUTEUR à laquelle a été coupée la bille.	OBSERVATIONS.
m	m	
0,62	1,48	Arbre crû dans un taillis, coupé en séve, écorcé et laissé quelque temps sur place.
0,70	0,74	Arbre crû dans un bon taillis, coupé en pleine séve et enlevé tout de suite de la forêt sans avoir été écorcé.
0,76	3,50	Arbre crû en massif serré, dans un terrain pierreux; coupé en séve, écorcé et laissé quelque temps sur place.
0,78	3,50	Arbre crû dans un terrain pierreux, et qui avait été dominé dans sa jeunesse; coupé en pleine séve et enlevé tout de suite de la forêt sans avoir été écorcé.
0,70	»	Arbre crû dans un mauvais taillis très-clair-planté, coupé en séve, écorcé et laissé quelque temps sur place; conservé entier.
0,58	0,74	Arbre crû dans un bon taillis, coupé en pleine séve et enlevé tout de suite de la foret sans avoir été écorcé.

RÉ.

Arbres coupés hors séve.

CIRCONFÉRENCE moyenne.	HAUTEUR à laquelle a été coupée la bille.	OBSERVATIONS.
m	m	
0,60	2,22	Arbre venu en massif peu serré, d'un accroissement médiocre.
0,67	1,50	Arbre isolé, très-branchu et d'un accroissement passable.
0,84	0,75	Arbre isolé, très-branchu et d'un bel accroissement.
0,79	2,96	Arbre venu en massif: a été serré longtemps; accroissement passable.
0,70	4,44	Arbre venu en massif, gêné par ses voisins, et d'un accroissement passable.
0,72	3,00	Arbre venu en massif serré, et d'un accroissement passable.
0,64	3,00	Arbre venu en massif, et d'un bon accroissement.
0,66	1,96	Arbre venu en massif, et d'un accroissement passable.
0,72	2,96	Arbre serré dans un grand taillis d'aune, venu à 1m,25 du ruisseau, et d'un accroissement passable.
0,54	1,48	Arbre venu en massif et d'un bon accroissement.
0,68	4,00	Arbre venu en massif, tordu, et d'un assez bon accroissement.
0,68	5,50	Arbre venu dans un taillis serré, à 1m,50 du ruisseau, et d'un bon accroissement.
0,63	»	Arbre conservé en entier: venu isolément et malade à sa base.

Arbres coupés hors séve.

CIRCONFÉRENCE moyenne.	HAUTEUR à laquelle a été coupée la bille.	OBSERVATIONS.
m	m	
0,62	4,00	Arbre isolé, mais qui avait été serré à une époque antérieure; accroissement médiocre.
0,60	3,00	Arbre venu en massif, et d'un accroissement passable.
0,72	5,30	Cet arbre a toujours été serré et dominé par un autre chêne plus âgé; accroissement médiocre.
0,71	2,70	Arbre venu en massif serré et d'un bel accroissement.
0,51	2,70	Arbre venu dans un taillis serré; faible accroissement.
0,80	2,70	Arbre venu dans un taillis serré, à 20 mètres d'un ruisseau, très-branchu, dominé, et d'un accroissement passable.
0,45	1,35	Arbre venu sur souche dans un taillis serré.
0,39	1,35	Arbre venu dans un taillis serré.

Tableau n° III. — *Inventaire des arbres coupés pour les e*

EXPOSITION.	NATURE DU TERRAIN.	NUMÉRO de l'arbre.	TEMPS écoulé depuis la coupe.	FORÊT OU L'ARB

CHÊNE.

EXPOSITION.	NATURE DU TERRAIN.	NUMÉRO de l'arbre.	TEMPS écoulé depuis la coupe.	FORÊT OU L'ARB
Est.........	Grès bigarré.	1	2 ans.	Sainte-Claire.
Est.........	Grès bigarré.	2	2 ans.	Sainte-Claire.
Nord.......	Grès vosgien.	3	2 ans.	Glissière.
Midi........	Grès vosgien.	4	2 ans.	Bergerie.
Midi........	Grès vosgien.	5	2 ans.	Fraize.
Sud-ouest...	Grès vosgien.	6	6 ans.	Charmille (au
Sud-est.....	Grès vosgien.	7	3 ans.	Hans-Sprung.
Nord.......	Grès vosgien.	8	2 ans.	Glissière.
Est.........	Grès bigarré.	9	2 ans.	Sainte-Claire.
Est.........	Grès bigarré.	10	2 ans.	Sainte-Claire.
Ouest.......	Grès bigarré.	11	3 ans.	Sainte-Claire.

SAPIN.

EXPOSITION.	NATURE DU TERRAIN.	NUMÉRO de l'arbre.	TEMPS écoulé depuis la coupe.	FORÊT OU L'ARB
Sud........	Grès vosgien.	1	1 an.	Mirguet.
Sud........	Grès vosgien.	2	1 an.	Mirguet.
Sud........	Grès vosgien.	3	1 an.	Rupt de Larô.
Nord.......	Grès vosgien.	4	1 an.	Rupt de Larô.
Nord.......	Grès vosgien.	5	1 an.	Rupt de Larô.
Nord.......	Grès vosgien.	6	1 an.	Rupt de Larô.
Nord-ouest..	Grès vosgien.	7	1 an.	Rougimont.
Nord-ouest..	Grès vosgien.	8	1 an.	Rougimont.
Nord-ouest..	Grès vosgien.	9	1 an.	Rougimont.
Nord-ouest..	Grès vosgien.	10	1 an.	Rougimont.
Nord-ouest..	Grès vosgien.	11	1 an.	Rougimont.
Nord-ouest..	Grès vosgien.	12	1 an.	Rougimont.
Nord-ouest..	Grès vosgien.	13	1 an.	Rougimont.

le rupture sur des échantillons employés dans la pratique.

LONGUEUR de la pièce.	ÉQUARRISSAGE DE LA PIÈCE.	DÉNOMINATION COMMERCIALE.
	CHÊNE.	
m	m m	
4,00	0,078 sur 0,080	Trafté ou chevron.
4,00	0,081 sur 0,082	Trafté ou chevron.
6,53	0,136 sur 0,161	Pièce de 5 à 6 (simple panne).
6,82	0,159 sur 0,189	Pièce de 6 à 7 (simple panne).
6,10	0,182 sur 0,210	Pièce de 7 à 8 (panne).
7,06	0,190 sur 0,220	Pièce de 7 à 8 (panne).
5,87	0,231 sur 0,253	Pièce de 8½ à 9½ (panne).
6,11	0,217 sur 0,237	Pièce de 8 à 9 (panne).
3,37	0,242 sur 0,028	Planche (entrevous).
3,65	0,143 sur 0,042	Planche (échantillon).
6,50	0,293 sur 0,054	Madrier (doublette).

	ÉTAT du peuplement.	LONGUEUR de la pièce.	ÉQUARRISSAGE de la pièce.	DÉNOMINATION COMMERCIALE.
			SAPIN.	
		m	m m	
bon,	Taillis.	10,47	0,176 sur 0,198	Pièce de 6 à 7 (simple panne).
bon,	Taillis.	10,36	0,088 sur 0,115	Chevron.
bon,	Massif un peu clair.	10,47	0,220 sur 0,245	Pièce de 8 à 9 (panne).
	Massif un peu clair.	10,42	0,223 sur 0,240	Pièce de 8 à 9 (panne).
	Massif un peu clair.	10,49	0,169 sur 0,196	Pièce de 6 à 7 (simple panne).
	Massif un peu clair.	10,56	0,094 sur 0,130	Chevron.
bon, sec.	Massif.	14,00	0,290 sur 0,324	Pièce de 11 à 12 (recharge).
bon, sec.	Massif.	10,50	0,096 sur 0,124	Chevron.
bon, sec.	Massif.	10,41	0,164 sur 0,194	Pièce de 6 à 7 (simple panne).
bon, sec.	Massif.	10,54	0,225 sur 0,243	Pièce de 8 à 9 (panne).
bon, sec.	Massif.	13,00	0,254 sur 0,283	Pièce de 9 à 10 (panne).
bon, sec.	Massif.	4,23	0,250 sur 0,057	Madrier.
bon, sec.	Massif.	4,24	0,242 sur 0,028	Planche.

Tableau n° IV.

ESSENCE.	NUMÉRO de la tringle.	SECTION de la tringle en millim. carrés.	DEGRÉ d'humidité en centièmes.	CHARGE en kilogram.	DISTANCE des points de repère en millimètres	
					avec charge.	sans charge.
					mm	mm
Charme..........	7. N. [2]	48,88	37,22	40	814,87	814,16
				80	815,70	814,28
Tremble.........	8. [1]	50,28	21,83	40	805,84	805,09
				80	806,43	805,08
				120	807,18	805,17
Aune............	12. [1]	51,47	28,55	40	797,09	796,21
				80	798,06	796,40
				120	799,23	796,60
Sycomore........	22. N. [3]	46.80	31,62	40	778,50	777,89
				80	779,14	777,92
				120	779,76	778,08
				160	780,49	778,15
Érable..........	23. N. [3]	47,02	13,79	40	814,55	813,75
				100	815,35	813,78
				160	816,50	813,81
Chêne	34. (1) [1]	46,37	10,96	40	781,02	780,49
				80	781,58	780,49
				140	782,55	780,54
Chêne...........	34. (1) E. [5]	40,55	10,96	40	808,90	808,12
				80	809,51	808,18
				120	810,21	808,18
				200	811,73	808,25
Chêne...........	34. (3) E. [2]	46,55	16,63	40	811,32	810,72
				100	812,10	810,71
				200	813,51	810,73
Chêne...........	34. (3) E. [4]	45,88	16,63	40	786,89	786,11
				100	787,98	786,21
Bouleau.........	39. [1]	51,37	37,83	40	791,75	790,98
				80	792,38	791,06
				120	793,14	791,07
Bouleau.........	39. N. [3]	42,77	10,67	40	807,88	807,41
				80	808,30	807,45
				140	809,00	807,53
				200	809,85	807,56
Hêtre...........	41. (1) E. [3]	49,19	18,22	40	782,58	781,93
				80	783,22	781,94
				120	783,85	781,93
				160	784,59	782,10
Chêne	45. E. [3]	98,68	19,53	80	814,26	813,68
				180	815,06	813,69
				300	815,93	813,72
				440	817,23	813,86
Frêne...........	57. [1]	53,78	31,50	40	804,31	803,69
				80	804,92	803,71
				120	805,71	803,80
Frêne...........	57. [1]	52,77	10,54	40	815,35	814,96
				80	815,93	815,02
				140	816,72	815,00
				200	817,48	814,97
				240	818,10	815,08
Orme............	58. N. [3]	47,26	33,26	40	797,16	796,40
				80	797,95	796,61
				140	799,20	796,80
				240	800,95	797,10
Peuplier	64. (1) [1]	36,76	17,21	40	793,05	791,63
				80	794,33	791,67

nent.

e.	NUMÉRO de la tringle.	SECTION de la tringle en millim. carrés.	DEGRÉ d'humidité en centièmes.	CHARGE en kilogram.	DISTANCE des points de repère en millimètres		ALLONGEMENT élastique par mètre, en millim.	COEFFICIENT d'élasticité.
					avec charge.	sans charge.		
					mm	mm	mm	
....	64. (3) [1]	49,52	17,21	40	781,95	781,10	1,088	722,5
				80	782,90	781,13	2,266	
....	66. (1) E. [2]	22,49	16,63	35	777,35	776,60	0,966	1418,8
				75	778,50	776,66	2,369	
				115	779,63	776,80	3,644	
				155	780,74	776,91	4,931	
....	66. (1) E. [4]	23,25	16,63	35	756,49	755,65	1,112	1463,6
				75	757,39	755,74	2,183	
				115	758,23	755,72	3,321	
				155	759,11	755,67	4,552	
....	18. (1) E. [2]	54,32	16,28	40	789,60	789,06	0,684	978,4
				60	789,81	789,06	0,950	
				80	790,08	789,01	1,356	
				120	790,96	789,09	2,370	
				160	791,68	789,08	3,295	
....	18. (1) E. [3]	45,07	16,28	40	799,22	798,66	0,701	1422,5
				80	799,74	798,69	1,315	
				120	800,08	798,70	1,728	
....	18. (1) E. [4]	46,74	16,28	40	792,32	791,82	0,631	1482,5
				80	792,81	791,84	1,225	
				120	793,12	791,76	1,718	
				180	793,86	791,89	2,488	
....	18. (1) E. [5]	45,16	16,28	40	790,25	789,77	0,608	1559,6
				80	790,71	789,77	1,190	
				120	791,14	789,79	1,709	
				180	791,81	789,87	2,456	
....	65. (5) [3]	106,60	10,26	95	824,79	824,13	0,801	1056,8
				135	825,10	824,15	1,153	
				175	825,39	824,18	1,468	
				215	825,72	824,14	1,917	
				255	826,06	824,14	2,330	
				295	826,43	824,19	2,718	
....	65. (6) [2]	104,95	10,26	95	728,04	727,30	1,017	927,9
				155	728,53	727,38	1,581	
				195	728,78	727,32	2,007	
				235	729,51	727,72	2,461	
				275	729,63	727,64	2,736	
....	65. (6) [5]	102,17	10,26	95	824,78	824,15	0,764	1253,4
				135	824,91	824,10	0,983	
				175	825,11	823,98	1,371	
				215	825,35	823,96	1,687	
				255	825,55	823,90	2,002	
				295	825,85	823,89	2,380	
				335	826,18	823,98	2,670	
				355	826,28	823,99	2,780	
				395	826,44	823,99	2,973	
....	31. (1) N. [3]	49,90	13,50	40	779,71	778,91	1,027	765,2
				60	780,02	778,90	1,438	
				80	780,68	778,91	2,272	
				120	781,42	778,99	3,120	
....	66. (2) O. [3]	23,30	15,66	40	797,25	796,38	1,092	1551,0
				80	798,23	796,46	2,222	
				120	799,17	796,52	3,327	

Tableau n° V. — *Détermination du degré d'humidité*

ESSENCE.	NUMÉRO de l'arbre.	BOIS VERT.	BOIS APRÈS QUELQUE TEMPS DE DÉPOT AU LABORATOIRE.				
		Quantité d'eau en centièmes.	Nombre de triangles.	Poids au moment de l'expérience en grammes.	Poids primitif en grammes.	Quantité d'eau en centièmes.	NOMBRE de triangles.
Charme......	7	37,22	"	"	"	"	2
Tremble.....	8	38,56	"	"	"	"	4
Aune........	12	28,55	"	"	"	"	3
Sycomore....	22	31,62	"	"	"	"	3
Érable.......	23	29,04	"	"	"	"	3
Chêne.......	34 (1)	17,40	7	492,37	484,07	19,08	17
Chêne.......	34 (3)	17,16	6	360,48	362,40	16,63	12
Chêne.......	45	44,83	6	686,85	919,44	19,53	17
Bouleau......	39	37,83	"	"	"	"	5
Hêtre........	41 (1)	19,46	5	251,30	254,47	18,22	12
Hêtre........	41 (3)	15,69	3	162,70	161,38	16,50	8
Hêtre........	46	22,41	4	211,04	230,63	13,92	10
Frêne........	57	31,50	"	"	"	"	2
Orme........	58	33,26	"	"	"	"	4
Peuplier.....	64 (1)	22,73	5	155,38	155,66	22,55	8
Peuplier.....	64 (3)						
Acacia.......	66	18,43	5	123,25	125,51	16,63	23
Sapin........	18 (1)	21,87	8	352,62	363,45	18,89	17
Sapin........	18 (3)	18,65	8	308,67	310,80	17,97	17
Sapin........	18 (5)	18,78	3	106,00	104,88	19,84	12
Sapin........	65	20,20	24	1912,00	1957,09	20,18	24
Pin..........	31 (1)	61,60	12	576,63	1061,87	15,90	12
Pin..........	3 (1)	"	5	254,71	508,66	11,68	"
Pin..........	31 (3)	14,07	4	155,52	154,65	14,63	9

le chacune des expériences relatives à leur élasticité.

ntité n en èmes.	BOIS DESSÉCHÉ À L'ÉTUVE, COMPARÉ AU BOIS VERT.					OBSERVATIONS.
	Nombre de tringles.	Poids au moment de l'expérience en grammes.	Poids primitif en grammes.	Quantité d'eau primitive en centièmes.	QUANTITÉ d'eau donnée par la dessiccat. absolue, en centièmes.	
,01	2	92,22	128,57	37,22	8,95	
,83	4	141,25	201,65	38,56	8,61	
,03	3	114,85	142,31	28,55	9,25	
,08	3	123,94	156,71	31,62	10,71	
,79	3	127,04	159,38	29,04	8,75	
,96	9	535,21	582,99	17,40	9,20	
,54	5	297,81	325,26	17,16	8,72	
,54	8	786,87	1223,28	44,83	9,16	Le poids absolu est calculé pour une section de $9^{mm},8$ de côté.
,67	5	251,21	352,88	37,83	9,02	
,94	6	277,88	307,70	19,46	9,77	
,83	4	211,02	229,53	15,69	7,63	
,49	5	284,11	326,15	22,41	9,52	
,54	2	95,64	124,03	31,50	8,61	
,17	4	193,73	255,05	33,26	9,22	
,21	5	142,18	160,41	22,73	11,37	
,66	10	226,29	247,61	18,43	9,82	
,28	7	308,56	353,63	21,87	9,13	
98	8	285,12	316,58	18,65	8,71	
51	8	325,33	357,48	18,78	9,79	
26	20	1351,51	1552,19	20,20	7,27	
50	5	224,43	472,86	61,60	9,07	Les deux lignes qui correspondent au dépôt au laboratoire proviennent de ce qu'on a pesé une seconde fois les tringles vertes au bout de quelques jours, à cause de la grande quantité d'humidité qu'elles contenaient d'abord.
	″	″	″	″	″	
77	5	166,56	173,70	14,07	9,96	Le bois dit VERT était déjà considérablement desséché.

Tableau n° VI. — *Degré d'humidi*

ESSENCE.	NUMÉRO de l'arbre.	QUANTITÉ D'EAU en centièmes.	OBSERVATIONS.
Hêtre...............	1	38,30	
Hêtre...............	6	42,37	
Hêtre...............	11	43,17	
Hêtre...............	27	37,42	
Hêtre...............	29	39,43	
Hêtre...............	32	38,21	
Hêtre...............	33	39,88	
Hêtre...............	41 (2)	39,38	
Hêtre...............	42	33,45	
Hêtre en séve........	44	42,58	
Hêtre........ N.-E.	46	33,07	
S.-E.		34,35	
N.-O.		34,87	
Hêtre...............	49	37,42	
Hêtre...............	53	39,10	
Hêtre...............	55	45,18	
Hêtre...............	60	37,15	
Hêtre...............	62	35,36	
Chêne.............	2	38,01	
Chêne.............	3	33,72	
Chêne.............	4	36,29	
Chêne.............	5	52,11	
Chêne.............	9	55,89	
Chêne.............	10	37,69	
Chêne.............	26	34,97	
Chêne.............	30	37,52	
Chêne.............	34 (2)	40,21	
Chêne.............	34 (4)	40,03	
Chêne.............	35	38,45	
Chêne.............	36	34,23	
Chêne.............	37	41,70	
Chêne en séve........	38	53,75	
Chêne en séve........	43	37,11	
Chêne........ N.-O.	45	44,64	
S.-E.		40,69	
N.-E.		41,72	
S.-O.		40,60	
Chêne...............	48	41,01	
Chêne...............	52	35,03	
Chêne...............	56	42,46	
Chêne...............	59	37,83	
Chêne...............	61	35,40	

moment des expériences par la flexion.

NCE.	NUMÉRO de l'arbre.	QUANTITÉ d'eau en centièmes.	OBSERVATIONS.
....	7	52,07	
....	40	30,37	
....	8	37,07	
....	12	54,46	
....	22	38,98	
....	23	38,21	
....	25	42,89	
....	39	34,05	
....	57	26,79	
....	58	36,30	
....	63 (1)	24,99	
....	63 (2)	24,26	
....	64 (2)	39,38	
....	64 (4)	"	Cette bille ayant été rompue pendant l'expérience n'a pas été conservée, mais elle devait contenir à peu près la même quantité d'eau hygrométrique que le morceau 64 (2) provenant du même arbre.
....	16	36,46	
....	17	42,11	
....	18 (2)	39,93	
....	18 (4)	34,92	
....	18 (6)	49,62	
....	19	38,78	
ve........	20	48,47	
ve........	21	45,07	
....	24	35,85	
....	28	32,72	
....	47	48,23	
....	51	52,57	
....	13	40,65	
....	14	42,31	
....	15	49,74	
....	31 (2)	45,44	
....	31 (4)	51,58	
....	50	42,29	
....	54	48,16	

Tableau n° VII. — *Rapports entre les vitesses du son et les coefficients*

ESSENCE.	NUMÉRO de l'arbre	NUMÉRO de la tringle.	QUANTITÉ d'eau.	COEFFICIENT d'élasticité donné par		RAPPORT	MOYENNE	VITESSE DU SON donnée par		RAPPORT	MOYENNE
				l'allongement.	les vibrations longitudinales.			l'allongement.	les vibrations longitudinales.		
Charme...	7	N. [1] [2]	37,22	636,8 938,5	795,6 902,3	1,249 0,961	1,106	8,86 10,39	9,90 10,19	1,117 0,980	1,048
Tremble..	8	N. [1] N. [2] N. [4]	38,58	725,0 1000,4 1020,2	671,2 1009,8 1220,0	0,926 1,009 1,196	1,044	11,81 13,80 12,80	11,36 13,86 14,00	0,962 1,004 1,094	1,023
Aune.....	12	N. [1] [3]	28,55	718,3 963,7	720,2 1118,8	1,003 1,137	1,070	11,15 12,94	11,17 13,80	1,002 1,066	1,034
Sycomore.	22	N. [1] [3]	31,62	706,9 1138,7	761,2 1400,4	1,077 1,232	1,154	10,78 12,20	11,18 13,54	1,038 1,110	1,074
Érable....	23	N. [1] [3]	13,79	983,0 1026,1	1002,2 1146,3	1,019 1,117	1,068	12,61 12,31	12,74 13,01	1,010 1,057	1,033
Chêne....	34 (1)	E. [2] [4] [5]	19,06	1111,8 1276,3 883,6	1236,8 1570,8 1086,9	1,112 1,229 1,230	1,190	11,74 11,75 11,74	12,38 13,02 13,01	1,054 1,108 1,108	1,090
Chêne...	34 (3)	E. [2] [3] [4]	16,63	1241,4 1086,7 853,6	1445,7 1088,2 1106,8	1,165 1,030 1,297	1,164	11,38 11,61 10,67	12,82 11,79 12,15	1,079 1,015 1,138	1,077
Chêne....	45	E. [3] [4] [5]	19,53	1096,1 441,0 506,1	924,2 478,4 585,0	0,844 1,085 1,158	1,029	11,76 8,66 8,83	10,81 9,02 9,51	0,919 1,041 1,077	1,012
Bouleau..	39	N. [1] [3] [5]	37,83	888,4 1178,4 699,0	1130,6 1298,7 976,7	1,272 1,102 1,397	1,257	10,04 11,48 8,83	11,33 12,05 10,44	1,128 1,049 1,182	1,120
Hêtre.....	41 (1)	E. [3] [4]	18,22	1018,9 985,6	950,6 1083,7	0,933 1,099	1,016	11,15 10,91	10,77 11,45	0,966 1,049	1,007
Hêtre.....	41 (3)	E. [3]	16,50	806,1	799,0	0,991	0,991	9,76	9,72	0,996	0,996
Hêtre.....	46	E. [2] [3] [4]	13,92	895,7 1164,2 899,5	1301,7 1260,4 1214,1	1,453 1,083 1,350	1,295	10,47 12,10 10,89	12,62 12,60 12,65	1,205 1,041 1,162	1,136
Frêne....	57	N. [1] [2]	31,50	959,0 1171,3	1216,7 1476,4	1,268 1,260	1,264	11,58 11,84	13,05 13,30	1,127 1,123	1,125
Orme.....	58	N. [1] [3]	23,26	435,1 1009,5	558,2 1248,7	1,283 1,237	1,260	8,02 11,25	9,08 12,51	1,132 1,112	1,122
Peuplier..	64 (1)	N. [2] [3]	22,55	535,1 612,5	496,6 580,2	0,928 0,947	0,937	12,00 12,52	11,56 12,19	0,963 0,974	0,968
Peuplier..	64 (3)	N. [4]	22,55	736,6	765,3	1,039	1,039	13,16	13,41	1,019	1,019
Acacia....	66 (1)	E. [2] [3] [4]	16,63	1418,8 1334,8 1465,0	1871,6 1639,0 1568,0	1,319 1,228 1,070	1,206	13,21 13,52 13,11	15,18 14,98 13,57	1,149 1,108 1,035	1,097

au moyen des vibrations longitudinales et les mêmes éléments ent.

– no re	NUMÉRO de la tringle.	QUANTITÉ d'eau.	COEFFICIENT d'élasticité donné par		RAPPORT	MOYENNE	VITESSE DU SON donnée par		RAPPORT	MOYENNE	MOY. GÉNÉRALES des rapports dans chaque essence	
			l'allongement.	les vibrations longitudinales.			l'allongement.	les vibrations longitudinales.			pour les coeffic. d'élasticité.	pour les vitesses du son.
	» »	» »	» »	» »	» »		» »	» »	» »		1,105	1048
	N. [1] [4]	21,83	935,1 1437,4	871,7 1615,0	0,932 1,123	1,027	13,80 15,57	13,33 16,50	0,966 1,059	1,012	1,035	1,017
	N. [3]	16,03	1086,2	1274,1	1,173	1,173	13,84	14,99	1,083	1,083	1,121	1,058
	N. [3]	15,08	1294,8	1457,1	1,125	1,125	13,72	14,56	1,061	1,061	1,139	1,067
	» »	» »	» »	» »	» »		» »	» »	» »		1,068	1,033
(1)	E. [1] [2] [3] [4] [5]	10,96	1205,6 1375,2 1241,3 1517,0 1151,0	1121,5 1425,8 1321,5 1520,0 1193,9	0,930 1,037 1,065 1,002 1,037	1,014	11,96 12,46 12,02 12,88 12,26	11,55 12,69 12,40 12,89 12,48	0,965 1,018 1,032 1,000 1,018	1,007	1,102	1,048
(3)	E. [1] [2] [3] [4]	8,54	1488,1 1390,2 1246,2 1060,2	1488,6 1478,7 1341,3 1255,5	1,000 1,064 1,076 1,184	1,081	13,38 12,65 12,73 12,15	13,38 13,05 13,21 13,22	1,000 1,032 1,038 1,088	1,039	1,122	1,058
	E. [1] [2] [3] [4] [5]	10,54	640,2 905,5 1194,1 974,1 556,6	1071,0 1239,0 1292,0 552,0 801,0	1,673 1,368 1,082 0,567 1,439	1,226	9,38 10,39 11,79 12,79 8,54	12,14 12,15 12,27 9,63 10,25	1,294 1,169 1,041 0,753 1,200	1,091	1,127	1,051
	N. [1] [3]	10,67	1288,9 1709,7	1558,1 1926,9	1,209 1,127	1,168	14,02 14,52	15,41 15,41	1,099 1,061	1,080	1,212	1,100
(1)	E. [2] [3] [4]	13,94	982,1 986,5 1060,9	1020,5 1070,1 1225,8	1,039 1,085 1,155	1,093	10,96 11,07 11,57	11,17 11,53 12,44	1,019 1,041 1,075	1,045	1,054	1,026
(3)	N. [2] [3]	11,83	1200,4 1142,5	1226,7 1287,1	1,022 1,126	1,074	11,43 11,97	11,56 12,70	1,011 1,061	1,036	1,032	1,016
	E. [2] [3] [4]	11,49	1134,2 1213,5 1072,0	1510,7 1359,9 1193,9	1,332 1,121 0,114	1,189	11,76 12,38 11,98	13,57 13,11 12,64	1,154 1,059 1,055	1,089	1,242	1,112
	N. [1] [2]	10,54	1264,3 1280,4	1409,2 1723,0	1,115 1,345	1,229	13,92 12,80	14,70 14,85	1,056 1,160	1,108	1,246	1,116
	N. [3]	9,17	1403,0	1530,2	1,090	1,090	13,85	14,46	1,044	1,044	1,175	1,083
(1)	N. [1] [2] [3] [4]	17,21	633,4 689,2 648,8 404,0	6 70 579,9 582,1 514,4	1,070 0,841 0,897 1,273	1,020	12,01 13,54 13,22 10,29	12,44 12,42 12,52 11,61	1,036 0,917 0,947 1,128	1,007	0,978	0,987
(3)	N. [1] [3]	17,21	722,4 794,5	785,3 813,4	1,087 1,024	1,055	13,74 14,06	14,33 14,23	1,043 1,012	1,027	1,047	1,025
(1)	E. [4]	15,66	1614,9	1878,0	1,163	1,287	13,39	14,43	1,077	1,081	1,193	1,091
(2)	O. [3] N. [3] [4]		1530,7 1279,7 1427,6	1632,0 1622,0 1688,0	1,065 1,267 1,182		14,31 13,21 13,46	14,77 14,88 14,64	1,032 1,126 1,087			
(3)	N. [1] [2] [3] [4]		1186,8 1359,3 1299,3 1345,6	1433,0 1669,0 1503,0 1578,0	1,207 1,227 1,156 1,172		12,48 13,33 13,08 12,99	13,71 14,77 14,07 14,07	1,098 1,108 1,075 1,083			

[Suite.] Tableau n° VII. — *Rapports entre les vitesses du son et les*

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ESSENCE.	NUMÉRO de l'arbre	NUMÉRO de la tringle.	QUANTITÉ d'eau.	COEFFICIENT d'élasticité donné par		RAPPORT	MOYENNE	VITESSE DU SON donnée par		RAPPORT	MOYENNE
				l'allongement.	les vibrations longitudinales.			l'allongement.	les vibrations longitudinales.		
Sapin.....	18 (1)	E. [2]	13,89	909,2	968,9	1,065	1,160	14,04	14,49	1,032	1,075
		[3]		1154,1	1388,6	1,203		14,69	16,12	1,097	
		[4]		1056,1	1443,0	1,366		13,67	15,98	1,169	
		[5]		1473,5	1482,9	1,006		15,79	15,84	1,003	
Sapin.....	18 (3)	E. [2]	17,97	853,3	914,0	1,071	1,018	14,13	14,63	1,035	1,009
		[5]		1385,1	1337,7	0,966		16,37	16,09	0,983	
Sapin.....	18 (5)	E. [2]	19,84	826,1	828,5	1,003	1,023	13,38	13,40	1.001	1,011
		[3]		1177,6	1207,2	1,025		14,86	15,04	1,012	
		[4]		1328,2	1384,6	1,042		15,98	16,32	1,021	
Sapin.....	65 (1)	[2]	10,26	613,8	664,8	1,083	1,051	11,02	11,47	1,041	1,024
		[3]		496,7	630,2	1,269		11,09	12,49	1,126	
		[4]		1331,7	1421,2	1,067		15,82	16,34	1,033	
		[5]		1285,0	1498,9	1,166		15,48	16,71	1,079	
	65 (2)	[2]		858,0	923,1	1,076		13,81	14,32	1,037	
		[4]		1168,9	1188,9	1,017		15,49	15,62	1,008	
		[5]		1464,5	1555,6	1,063		16,75	17,26	1,030	
	65 (3)	[2]		1096,0	1053,0	0,961		14,43	14,14	0,979	
		[4]		1378,6	1276,7	0,926		16,28	15,67	0,962	
		[5]		1335,0	1364,7	1,022		16,45	16,62	1,010	
	65 (4)	[3]		1085,7	1167,1	1,075		14,34	14,87	1,037	
		[4]		1365,2	1413,2	1,035		15,25	15,51	1,017	
		[5]		1290,5	1446,6	1,121		15,28	16,18	1,059	
	65 (5)	[2]		858,1	941,2	1,097		13,12	13,74	1,047	
		[3]		1053,2	972,1	0,923		14,82	14,24	0,961	
		[4]		1056,8	1016,2	0,961		14,25	13,96	0,981	
	65 (6)	[1]		1156,3	1212,0	1.048		15,11	15,47	1,024	
		[2]		928,3	871,3	0,938		14,54	14,09	0,969	
		[3]		883,2	1019,3	1,154		13,97	15,01	1.074	
		[4]		1154,0	1180,4	1,023		15,07	15,25	1,012	
		[5]		1253,4	1306,3	1,042		15,59	15,92	1,021	
Pin.......	31 (1)	E. [2]	11,65	540,6	610,7	1,130	1.172	10,58	11,25	1,063	1,083
		[3]		592,2	689,0	1,163		10,79	11,64	1,079	
		[4]		606,3	742,2	1,224		11,34	12,55	1.106	
Pin.......	31 (3)	E. [2]	14,63	607,6	666,6	1,097	1,105	11,71	12,26	1.047	1,050
		[3]		696,2	774,8	1,113		12,11	12,77	1,054	

déterminés au moyen des vibrations longitudinales et les mémes gement.

u- RO le bre	NUMÉRO de la tringle.	QUANTITÉ d'eau.	COEFFICIENT d'élasticité donné par		RAPPORT	MOYENNE	VITESSE DU SON donnée par		RAPPORT	MOYENNE	MOY. GÉNÉRALES des rapports dans chaque essence	
			l'allongement.	les vibrations longitudinales.			l'allongement.	les vibrations longitudinales.			pour les coeffic. d'élasticité.	pour les vitesses du son.
(1)	E. [2]		978,4	1265,0	1,293		13,39	15,22	1,137			
	[3]		1422,5	1557,0	1,094		15,68	16,41	1,046			
	[4]		1482,5	1483,0	1,000		15,90	15,91	1,001			
	[5]		1559,6	1653,0	1,060		16,08	16,55	1,029			
	S. [2]	16,28	1173,1	1313,0	1,119	1,083	14,81	15,67	1,058	1,039	1,121	1,057
	[3]		1291,6	1386,0	1,073		15,05	15,57	1,035			
	[4]		1367,1	1435,0	1,050		15,39	15,76	1,024			
	[5]		1570,6	1526,0	0,972		16,35	16,11	0,985			
(3)	E. [2]		1053,2	1079,0	1,024		15,20	15,39	1,013			
	[3]		1408,5	1325,0	0,941	1,039	16,15	15,66	0,969	1,019	1,028	1,014
	[4]	15,98	1382,6	1465,0	1,059		16,08	16,55	1,029			
	[5]		1334,5	1512,0	1,133		15,82	16,84	1,064			
(5)	S. [2]		1407,6	1345,3	0,956		15,59	15,24	0,977			
	[3]	14,51	1183,2	1358,2	1,148	1,048	14,20	15,22	1,072	1,023	1,035	1,017
	[4]		1340,3	1393,7	1,040		15,92	16,23	1,019			
	»	»	»	»	»		»	»	»			
	»	»	»	»	»		»	»	»			
	»	»	»	»	»		»	»	»			
	»	»	»	»	»		»	»	»			
	»	»	»	»	»		»	»	»			
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	»	»	»	»	»		»	»	»			
	»	»	»	»	»		»	»	»		1,051	1,024
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	»	»	»	»	»		»	»	»			
	»	»	»	»	»		»	»	»			
	»	»	»	»	»		»	»	»			
	»	»	»	»	»		»	»	»			
	»	»	»	»	»		»	»	»			
	»	»	»	»	»		»	»	»			
	»	»	»	»	»		»	»	»			
	»	»	»	»	»		»	»	»			
	»	»	»	»	»		»	»	»			
	»	»	»	»	»		»	»	»			
	»	»	»	»	»		»	»	»			
(1)	[1]		623,7	646,5	1,036		10,79	10,99	1,018			
	E. [2]		616,5	679,9	1,102		11,12	11,68	1,050			
	[3]		704,2	774,9	1,100		11,36	11,92	1,049			
	[4]		706,9	853,6	1,207		11,65	12,80	1,098			
	S. [3]	13,30	682.8	804,8	1,178	1,121	10,74	11,66	1,086	1,058	1,146	1,070
	[4]		883,0	933,5	1,057		11,88	12,21	1,028			
	N. [2]		563,7	721,9	1,281		10,54	11,94	1,133			
	[3]		765,2	846,3	1,106		12,01	12,62	1.051			
	[4]		845,7	868,8	1,027		12,25	12,41	1,013			
(3)	S. [2]		850,4	908,5	1.068		12,69	13.12	1,034			
	[3]	9,77	795,4	850,0	1,069	0,949	12,81	13,24	1,034	0,971	1,027	1,010
	N. [3]		909,6	647,6	0,712		13,17	11,11	0,844			

Tableau n° VIII.— *Poids spécifique, vitesse du son, coefficient d'élasticité et*

ESSENCE.	NUMÉRO de l'arbre.	QUANTITÉ d'eau.	NUMÉRO de la couche.	POIDS SPÉCIFIQUE.					VITESSE D		
				E.	S.	O.	N.	Moyenne.	E.	S.	O.
Chêne.......	34 (1)	19,18	2	0,717	0,713	»	»	0,715	12,38	12,67	»
			4	0,823	0,777	»	»	0,800	13,02	13,09	»
			5	0,570	0,612	»	»	0,591	13,01	12,87	»
		17,40	2	0,829	0,702	0,736	0,769	0,759	11,97	13,65	13,61
			3	0,745	0,799	0,800	0,851	0,799	12,10	14,48	13,33
			4	0,725	0,746	0,710	0,697	0,719	12,33	12,88	13,67
			5	0,614	0,569	0,654	0,620	0,614	11,80	12,67	12,80
		10,96	2	0,787	0,793	0,817	0,698	0,774	12,69	14,30	14,53
			3	0,764	0,820	0,787	0,780	0,789	12,40	15,07	13,95
			4	0,813	0,707	0,756	0,696	0,743	12,89	13,58	14,20
			5	0,681	0,633	0,585	0,620	0,627	12,48	13,46	13,62
		9,20	2	»	»	0,779	0,738	0,758	»	»	14,92
			3	»	»	0,750	0,754	0,752	»	»	14,78
			4	»	»	0,730	0,719	0,724	»	»	14,22
			5	»	»	0,627	0,683	0,655	»	»	13,56
Chêne.......	34 (3)	17,16	2	0,729	0,728	0,819	0,730	0,751	12,21	13,12	12,30
			3	0,822	0,742	0,753	0,681	0,749	12,42	11,46	11,26
			4	0,661	0,689	»	0,574	0,641	12,55	12,19	»
		16,63	2	0,782	0,749	»	»	0,765	12,82	13,20	»
			3	0,696	0,727	»	»	0,711	11,79	12,21	»
			4	0,666	0,593	»	»	0,629	12,15	11,92	»
		8,72	2	»	»	0,723	0,713	0,718	»	»	12,84
			3	»	»	0,671	0,690	0,680	»	»	10,73
		8,54	2	0,772	0,748	0,766	0,767	0,763	13,05	13,92	12,88
			3	0,683	0,796	0,728	0,763	0,742	13,21	12,19	11,38
			4	0,638	0,618	»	0,625	0,627	13,22	13,09	»
Chêne.......	45	44,83	2	0,831	0,919	0,795	0,797	0,832	9,86	9,48	9,92
			3	0,774	0,931	»	»	0,852	10,20	9,13	»
			4	0,627	»	0,604	0,825	0,685	7,74	»	8,56
			5	0,602	0,631	0,634	0,674	0,635	8,22	7,80	8,34
			6	»	0,710	0,546	0,561	0,605	»	6,85	9,73
		19,53	3	0,703	0,700	»	»	0,701	10,81	10,71	»
			5	0,575	0,585	»	»	0,580	9,51	9,73	»
		10,54	2	0,746	0,712	0,691	0,622	0,643	12,15	11,94	12,12
			3	0,763	0,636	»	»	0,699	12,27	12,37	»
			4	0,529	»	0,506	0,647	0,561	9,63	»	10,61
			5	0,678	0,527	0,525	0,485	0,554	10,25	9,79	10,33
			6	»	0,497	0,485	0,464	0,482	»	8,93	11,62
		9,16	2	»	»	0,754	0,650	0,702	»	»	13,30
			5	»	»	0,629	0,546	0,587	»	»	11,28
			6	»	»	0,528	0,519	0,523	»	»	11,02
Hêtre.......	41 (1)	19,46	2	0,786	0,703	0,760	0,732	0,745	10,49	9,00	8,86
			3	0,744	0,734	0,801	0,724	0,751	11,16	9,10	10,14
			4	0,731	0,700	0,700	0,717	0,712	11,93	12,15	10,59
		18,22	3	0,728	0,747	»	»	0,737	10,77	9,43	»
			4	0,735	0,678	»	»	0,707	11,45	11,63	»
		13,94	2	0,727	0,699	0,762	»	0,729	11,17	9,39	9,26
			3	0,715	0,738	0,754	0,654	0,716	11,53	10,26	10,56
			4	0,704	0,705	0,734	0,691	0,708	12,44	12,91	11,47
		9,77	2	»	»	»	0,779	0,779	»	»	8,83
			4	»	»	0,727	0,692	0,709	»	»	11,28
Hêtre.......	41 (3)	16,50	3	0,732	0,769	»	»	0,760	9,72	10,42	»
		15,69	2	»	0,784	0,780	0,831	0,798	»	9,90	10,20
			3	0,748	0,688	0,721	0,677	0,708	11,00	11,91	11,17
		11,83	2	»	0,747	0,762	0,816	0,775	»	10,07	10,67
			3	0,786	0,743	0,757	0,709	0,749	11,46	12,04	11,40
		7,63	2	»	»	0,768	0,796	0,782	»	»	10,46
			3	»	»	0,715	0,677	0,696	»	»	10,50
Hêtre.......	46	22,41	2	0,768	»	»	0,800	0,784	10,38	»	»
			3	»	0,717	0,683	0,686	0,695	10,99	9,50	10,10
			4	0,686	0,668	0,679	0,657	0,672	10,17	9,59	10,28
		13,92	4	0,674	0,669	»	»	0,671	12,65	11,98	»
		11,49	2	0,729	»	»	0,767	0,748	13,57	»	»
			3	0,703	0,790	0,749	0,770	0,753	13,11	11,00	12,41
			4	0,664	0,741	0,648	0,713	0,691	12,64	11,88	12,76
		9,52	3	»	»	0,709	0,674	0,691	»	»	11,81
			4	»	»	0,658	0,700	0,679	»	»	11,92
Acacia.......	66 (1)	18,43	3	0,738	0,668	0,762	»	0,723	14,21	14,77	14,22
			4	0,790	0,796	0,822	»	0,803	13,99	14,53	12,65
		16,63	3	0,649	0,647	»	»	0,648	14,98	13,85	»
			4	0,757	0,706	»	»	0,731	13,57	13,79	»
		15,66	3	0,698	0,665	0,711	»	0,691	14,79	14,53	14,29
			4	0,801	0,729	0,730	»	0,753	14,43	14,77	12,66

bres, dans les mêmes couches et dans la direction des quatre points cardinaux.

IENT D'ÉLASTICITÉ.			COHÉSION PAR MILLIMÈTRE CARRÉ.					OBSERVATIONS.
O.	N.	Moyenne.	E.	S.	O.	N.	Moyenne.	
»	»	1262,8	2,90	7,22	»	»	5,06	
»	»	1534,1	9,67	8,15	»	»	8,91	
»	»	1114,1	5,41	7,54	»	»	6.47	
1334,2	1602,5	1488,8	»	»	»	»	»	
1599,7	1448,9	1540,3	»	»	»	»	»	
1493,1	1039,0	1291,7	»	»	»	»	»	
1205,9	902,0	1051,5	»	»	»	»	»	
1940,8	1628,3	1705,1	2,20	5,29	9,69	3,85	5,26	
1723,4	1575,2	1404,0	6,62	9,69	7,05	3,52	6,72	
1714,6	1188,3	1472,4	7,53	9,03	11,45	7,49	8,87	
1220,8	998,3	1176,0	8,39	9,03	7,49	5,85	7,69	
1950,5	1411,6	1681,0	»	»	»	»	»	
1843,0	1228,2	1535,6	»	»	»	»	»	
1640,3	1388,3	1624,3	»	»	»	»	»	
1296,8	1139,1	1217,9	»	»	»	»	»	
1394,4	1230,8	1314,6	»	»	»	»	»	
1074,3	1247,8	1214,2	»	»	»	»	»	
»	947,3	1090,4	»	»	»	»	»	
»	»	1456,9	6,45	5,00	»	»	5,72	
»	»	1153,5	5,32	7,34	»	»	6,33	
»	»	1027,8	5,67.	4,33	»	»	5,00	
1342,5	1395,3	1368,9	»	»	»	»	»	
1355,2	1121,1	1238,6	»	»	»	»	»	
1430,6	1410,1	1487,6	9,43	7,16	5,82	5,37	6,94	
1060,3	1586,1	1329,7	5,70	5,37	9,40	6,27	6,68	
»	1171,6	1206,1	4,50	7,61	»	5,82	5,98	
881,0	792,3	877,8	»	»	»	»	»	
»	»	880,4	»	»	»	»	»	
498,6	805,6	575,6	»	»	»	»	»	
495,8	412,3	449,3	»	»	»	»	»	
581,5	492,1	416,3	»	»	»	»	»	
»	»	913,9	6,72	5,04	»	»	5,88	
»	»	604,1	2,98	4,62	»	»	3,80	
1141,0	1031,0	1138,0	3,05	4,21	5,77	3,99	4,25	
»	»	1193,0	4,52	3,14	»	»	3,83	
641,0	990,0	728,0	2,23	»	3,14	6,21	3,86	
630,0	526,0	631,0	4,11	3,55	3,11	3,14	3,48	
737,0	395,0	526,0	»	2,66	3,10	1,72	2,49	
1301,6	1227,0	1364,3	»	»	»	»	»	
898,0	668,0	783,0	»	»	»	»	»	
722,2	490,0	606,1	»	»	»	»	»	
671,4	543,1	707,1	»	»	»	»	»	
926,8	1188,9	960,6	»	»	»	»	»	
885,7	1060,6	1087,9	»	»	»	»	»	
»	826,5	849,1	6,91	5,89	»	»	6,40	
»	1057,9	1087,9	3,48	5,81	»	»	4,64	
735,3	»	826,5	3,79	5,12	4,27	4,27	4,86	
947,1	1161,3	1013,3	7,75	5,12	7,26	3,42	5,89	
1087,1	1120,8	1188,8	6,52	4,70	7,31	5,55	6,02	
»	654,1	654,1	»	»	»	»	»	
1041,4	1210,3	1125,8	»	»	»	»	»	
»	»	869,2	2,41	5,87	»	»	4,14	
913,2	1200,5	992,8	»	»	»	»	»	
1010,9	1152,7	1070,0	»	»	»	»	»	
976,7	1226,7	1018,7	»	4,83	4,83	5,93	5,19	
1106,4	1287,1	1191,9	6,01	5,49	7,46	7,32	6,57	
946,4	1130,2	1038,3	»	»	»	»	»	
887,4	1297,4	1092,4	»	»	»	»	»	
»	951,4	959,3	»	»	»	»	»	
784,0	686,5	732,9	»	»	»	»	»	
807,1	698,5	748,8	»	»	»	»	»	
»	»	1147,0	4,28	2,86	»	»	3,57	
»	1311,9	1411,3	8,33	»	»	8,08	8,20	
1298,0	1237,9	1242,7	4,58	4,04	8,08	4,94	5,41	
1187,5	1144,5	1175,8	4,74	5,39	6,29	4,04	5,11	
1113,7	973,0	1043,3	»	»	»	»	»	
1052,8	851,1	951,9	»	»	»	»	»	
1734,0	»	1684,3	»	»	»	»	»	
1480,0	»	1703,0	»	»	»	»	»	
»	»	1517,8	6,26	11,59	»	»	8,92	
»	»	1539,8	9,25	9,06	»	»	9,15	
1634,0	»	1644,1	8,49	13,58	»	»	11,03	
1316,0	»	1661,1	7,20	11,45	10,21	»	9,62	

[Suite.] **Tableau n° VIII. —** ***Poids spéc., vitesse du son, coeffic. d'élast.***

ESSENCE.	NUMÉRO de l'arbre.	QUANTITÉ d'eau.	NUMÉRO de la couche.	POIDS SPÉCIFIQUE.					VITE	
				E.	S.	O.	N.	Moyenne.	E.	S.
Acacia.......	66 (2)	18,43	3	»	»	0,695	0,654	0,674	»	»
			4	»	»	0,719	0,671	0,695	»	13,63
		15,66	3	»	»	0,673	0,651	0,662	»	»
			4	»	0,757	0,709	0,700	0,722	»	13,85
		9,82	3	»	»	0,678	0,630	0,654	»	»
			4	»	»	0,711	0,736	0,723	»	»
Acacia.......	66 (4)	18,43	4	»	»	0,704	0,754	0,729	»	»
		15,66	4	»	»	0,718	0,734	0,726	»	»
Sapin.......	18 (1)	21,87	2	0,424	0,421	0,395	0,380	0,405	14,01	14,80
			3	0,462	0,432	0,561	0,545	0,500	15,72	14,81
			4	0,494	0,468	0,586	0,438	0,496	15,11	14,98
			5	0,508	0,512	0,521	0,493	0,508	15,85	15,20
		18,89	2	0,410	0,403	»	»	0,406	14,49	15,15
			3	0,475	0,435	»	»	0,455	16,12	15,47
			4	0,502	0,464	»	»	0,483	15,98	14,01
			5	0,525	0,556	»	»	0,540	15,84	15,11
		16,28	2	0,485	0,475	0,434	0,402	0,449	15,22	15,67
			3	0,514	0,508	0,539	0,481	0,510	16,41	15,57
			4	0,521	0,513	0,572	0,461	0,517	15,91	15,76
			5	0,536	0,522	0,517	0,529	0,526	16,55	16,11
		9,13	4	»	»	0,540	0,544	0,542	»	»
			5	»	»	0,526	0,500	0,513	»	»
Sapin.......	18 (3)	18,65	2	0,407	0,520	0,375	0,592	0,473	15,22	13,44
			3	0,462	0,514	0,476	0,499	0,488	15,25	14,48
			4	0,447	0,473	0,555	»	0,492	15,84	14,42
			5	0,458	0,468	0,452	0,453	0,458	16,27	15,76
		17,97	2	0,377	0,394	»	»	0,385	14,68	12,26
			3	0,474	0,480	»	»	0,477	15,45	15,16
			4	0,500	0,509	»	»	0,504	15,60	14,87
			5	0,459	0,425	»	»	0,442	16,09	16,56
		15,98	2	0,405	0,532	0,425	0,461	0,455	15,39	13,80
			3	0,480	0,459	0,494	0,540	0,493	15,66	14,87
			4	0,475	0,547	0,526	0,477	0,506	16,55	14,82
			5	0,474	0,494	0,468	0,485	0,480	16,84	16,14
		8,71	2	»	»	0,365	0,399	0,372	»	»
			4	»	»	0,590	0,473	0,531	»	»
			5	»	»	0,488	0,491	0,489	»	»
Sapin.......	18 (5)	18,78	2	0,393	0,541	»	0,397	0,413	13,91	14,93
			3	0,482	0,429	0,409	0,427	0,432	14,76	14,91
			4	0,436	0,419	0,415	0,430	0,425	16,19	16,06
		14,51	2	0,422	0,515	»	0,467	0,468	14,49	15,24
			3	0,496	0,521	0,444	0,511	0,493	14,77	15,22
			4	0,468	0,470	0,455	0,465	0,464	16,37	16,23
		9,79	2	»	0,434	»	0,471	0,452	»	15,85
			3	»	0,456	0,486	0,431	0,458	»	16,27
			4	»	0,471	»	0,508	0,489	»	17,23
Pin.........	31 (1)	61,60	2	0,873	»	0,566	0,828	0,756	7,35	»
			3	0,903	0,986	0,663	0,959	0,878	7,44	7,83
			4	0,979	1,013	0,701	1,025	0,929	7,57	8,26
		15,90	2	0,408	»	0,609	0,452	0,490	10,99	»
			3	0,513	0,420	0,451	0,427	0,453	11,37	10,74
			4	0,463	0,507	0,517	0,435	0,480	12,07	11,55
		13,50	2	0,443	»	0,560	0,430	0,484	11,68	»
			3	0,485	0,526	0,494	0,472	0,494	11,92	11,66
			4	0,463	0,556	0,473	0,501	0,498	12,80	12,21
		11,68	3	0,452	0,552	»	»	0,502	11,64	11,08
			4	0,419	0,421	»	»	0,420	12,55	11,64
		9,97	2	»	»	0,488	0,463	0,475	»	»
			3	»	»	0,539	0,528	0,533	»	»
			4	»	»	0,580	0,527	0,553	»	»
Pin.........	31 (3)	14,63	2	0,394	0,427	»	»	0,410	12,26	»
			3	0,422	0,471	»	»	0,446	12,77	11,98
		14,07	2	0,417	0,438	0,429	0,633	0,479	11.76	12,54
			3	0,435	0,438	0,584	0,421	0,469	11,69	12,14
		9,96	2	»	»	0,439	0,494	0,466	»	»
			3	»	»	0,489	0,506	0,497	»	»
		9,77	2	0,423	0,469	0,435	0,430	0,439	12,04	13,12
			3	0,439	0,431	0,421	0,466	0,439	12,59	13,24

fibres, dans les mêmes couches et dans la direction des quatre points cardinaux.

FICIENT D'ÉLASTICITÉ.			COHÉSION PAR MILLIMÈTRE CARRÉ.					OBSERVATIONS.
O.	N.	Moyenne.	E.	S.	O.	N.	Moyenne.	
1676,0	1592,0	1634,0	»	»	»	»	»	
1504,0	1565,0	1583,3	»	»	»	»	»	
1652,0	1622,0	1637,0	»	»	»	10,30	10.30	
1483,0	1688,0	1601,3	»	11,04	8,66	»	9,85	
1984,0	1790,0	1887,0	»	»	»	»	»	
2161,0	1995,0	2078,0	»	»	»	»	»	
1728,0	1708,0	1717,0	»	»	»	»	»	
1762,0	1743,0	1752,5	»	»	10,19	13.58	11,88	
988,1	909,0	967,8	»	»	»	»	»	
1343,9	1780,9	1368.2	»	»	»	»	»	
1062.1	1155,3	1167,1	»	»	»	»	»	
1463,7	1441,7	1422,1	»	»	»	»	»	
»	»	1004,9	4.32	4.11	»	»	4,21	
»	»	1280,2	4.88	4,92	»	»	4,90	
»	»	1233,6	4.30	6,34	»	»	5,32	
»	»	1455,7	5,81	5.42	»	»	5,61	
1202,6	1063,4	1211.0	4,23	3,93	4,89	4,68	4,43	
1596,0	1726,6	1551,4	4,22	3,77	4,68	5,96	4,66	
976,5	1350,0	1311,1	4,71	5,39	3,83	5,53	4,87	
1550,2	1689,7	1604,7	6,42	11,40	8,72	7.23	8,44	
1025,5	1693,8	1359,6	»	»	»	»	»	
1697.7	1642,5	1670,1	»	»	»	»	»	
667,8	»	966.4	»	»	»	»	»	
1331,5	»	1249,6	»	»	»	»	»	
1585.9	»	1318.3	»	»	»	»	»	
1247.5	1440,0	1340,0	»	»	»	»	»	
»	»	790,2	2,98	»	»	»	2,98	
»	»	1257,3	3,69	3,12	»	»	3,41	
»	»	1317,7	4,25	4,28	»	»	4,26	
»	»	1324,6	4.76	3,90	»	»	4,33	
802,2	890,6	977,9	4,51	3,26	4,24	3,46	3,87	
1443,4	1885,3	1448,7	5,33	6,25	4,45	5,55	5,39	
1590,1	1477,1	1471,3	8,26	5,98	7,99	6.30	7.13	
1381,2	1608,4	1487.1	7,82	6,95	5,56	7,01	6,83	
748,3	1089,5	919.0	»	»	»	»	»	
1739,3	1610,9	1685,1	»	»	»	»	»	
1660,8	1729,8	1695,3	»	»	»	»	»	
»	858,2	948,8	»	»	»	»	»	
969,8	1033,5	1071,3	»	»	»	»	»	
1126,4	1240,3	1217,2	»	»	»	»	»	
»	1044,6	1129,0	2,67	3,64	»	4,09	3,47	
1084,0	1288,2	1236,8	4.79	5,46	4,98	5.91	5,28	
1263,0	1405.7	1368,3	7,34	5,46	5.56	5.46	5,93	
»	1030,7	1129,3	»	»	»	»	»	
1141,8	1409,4	1303,2	»	»	»	»	»	
»	1496,4	1534,6	»	»	»	»	»	
410,1	582,8	507.8	»	»	»	»	»	
390.7	653,2	571,4	»	»	»	»	»	
471,2	681,9	640.6	»	»	»	»	»	
536,2	612,6	567,8	»	»	»	»	»	
434.1	682,2	601,9	»	»	»	»	»	
565,2	673,3	689,8	»	»	»	»	»	
595,7	721,9	665,8	2,47	»	1,20	1,40	1,69	
654,4	846,3	745,1	2,00	2,24	1,60	4,41	2,56	
600,3	868,6	814,0	2,45	3,31	3,01	2,20	2,74	
»	»	726,0	3,21	4,96	»	»	4,08	
»	»	692,3	2,86	3,98	»	»	3,42	
460,9	824,3	642,6	»	»	»	»	»	
577,2	1022,4	799,8	»	»	»	»	»	
949.7	1002,0	975,8	»	»	»	»	»	
»	»	666,6	2,19	3,42	»	»	2,81	
»	»	767,9	2,64	3,04	»	»	2,84	
580,1	579,9	646,0	»	»	»	»	»	
590,6	520,8	635,9	»	»	»	»	»	
673,5	756,2	714,8	»	»	»	»	»	
732,8	970,4	861,6	»	»	»	»	»	
710,6	673,3	745,7	1,66	1,65	1,61	1,61	1,63	
677,9	647,6	739,5	1.93	2,35	1.21	1,82	1,83	

Tableau nº IX. — *Propriétés mécanique*

ESSENCE.	NUMÉRO de l'arbre.	QUANTITÉ d'eau.	DENSITÉ DES COUCHES.					VITESSE DU SON DA		
			1.	2.	3.	4.	5.	1.	2.	3.
Charme	7	37,22	0,721	0,772	"	"	"	9,90	10,19	"
		11,01	0,571	0,650	"	"	"	12,91	12,55	"
		8,95	0,566	0,594	"	"	"	13,30	12,96	"
Tremble.....	8	38,56	0,462	0,467	0,496	0,553	"	11,36	13,86	13,4
		21,83	0,436	0,498	0,486	0,527	"	13,33	15,58	15,4
		8,61	0,421	0,502	0,473	0,521	"	14,85	15,16	16,1
Aune........	12	28,55	0,513	0,547	0,522	"	"	11,17	14,06	13,8
		16,03	0,490	0,525	0,504	"	"	13,05	15,12	14,9
		9,25	0,453	0,501	0,475	"	"	15,09	14,97	15,3
Sycomore....	11	31,62	0,541	0,605	0,679	"	"	11,18	13,14	13,5
		15,08	0,521	0,569	0,611	"	"	12,53	14,24	14,5
		10,71	0,505	0,533	0,613	"	"	13,97	14,13	13,5
Érable.......	13	29,04	0,583	0,630	0,630	"	"	11,28	11,41	11,7
		13,79	0,549	0,584	0,602	"	"	12,74	13,13	13,0
		8,75	0,518	0,592	0,607	"	"	13,90	13,63	13,9
Chêne.......	3	19,08	"	0,715	0,813	0,800	0,591	"	12,52	14,5
		17,40	0,757	0,759	0,799	0,719	0,614	11,44	13,21	13,0
		10,96	0,749	0,774	0,789	0,743	0,627	11,55	13,98	13,5
		9,20	0,707	0,758	0,752	0,724	0,655	15,23	13,98	13,4
Chêne.......	34 (3)	17,16	0,713	0,751	0,749	0,641	"	12,58	12,47	11,9
		16,63	"	0,765	0,711	0,629	"	"	13,01	12,0
		8,72	0,677	0,718	0,680	"	"	13,76	13,01	11,3
		8.54	0,739	9,763	0,742	0,627	"	13,38	13,16	12,5
Chêne.......	45	44,83	0,726	0,832	0,852	0,685	0,635	9,84	9,66	9,6
		"	"	"	"	"	0,605	"	"	"
		19,53	"	"	0,701	0,523	0,580	"	"	10,7
		"	"	"	"	"	0,531	"	"	"
		10,54	0,646	0,693	0,699	0,561	0,554	12,14	12,09	12,3
		"	"	"	"	"	0,482	"	"	"
		9,16	0,692	0,702	"	0,713	0,587	12,37	13,12	"
		"	"	"	"	"	0,523	"	"	"

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des fibres et à différents degrés d'humidité.

ENT D'ÉLASTICITÉ DES COUCHES.				COHÉSION DES COUCHES PAR MILLIMÈTRE CARRÉ.				
	3.	4.	5.	1.	2.	3.	4.	5.
2,3	″	″	″	2,60	2,86	″	″	″
2,1	″	″	″	2,82	3,31	″	″	″
2,1	″	″	″	″	″	″	″	″
9,8	1010,9	1220,0	″	1,30	4,08	″	2,66	″
9,5	1312,0	1615,0	″	3,18	5,54	6,60	7,60	″
8,6	1380,0	1669,3	″	″	″	″	″	″
6,7	1118,8	″	″	3,11	4,39	3,82	″	″
0,6	1274,1	″	″	3,16	4,53	4,96	″	″
3,6	1265,0	″	″	″	″	″	″	″
4,8	1400,4	″	″	2,26	6,33	7,27	″	″
8,9	1457,1	″	″	3,19	7,08	5,44	″	″
6,2	1263,1	″	″	″	″	″	″	″
3,2	978,0	″	″	1,54	1,30	1,56	″	″
6,5	1146,3	″	″	4,05	5,07	5,10	″	″
7,8	1330,3	″	″	″	″	″	″	″
2,8	1925,1	1534,1	1114,1	″	5,06	6,90	8,90	6,47
8,8	1540,3	1291,7	1051,5	″	″	″	″	″
5,1	1654,0	1472,4	1176,0	4,31	5,26	6,72	8,87	7,69
1,0	1535,6	1624,3	1217,9	″	″	″	″	″
4,6	1214,2	1090,4	″	″	″	″	″	″
6,9	1153,5	1027,8	″	″	5,72	6,33	5,00	″
8,9	1238,6	″	″	″	″	″	″	″
7,6	1329,7	1206,1	″	2,72	6,94	6,68	5,98	″
7,8	889,4	575,6	449,3	″	″	″	″	″
″	″	″	416,3	″	″	″	″	″
″	913,9	478,4	604,1	″	″	5,88	5,04	3,80
″	″	″	462,8	″	″	″	″	4,20
8,0	1193,0	728,0	631,0	2,49	4,25	3,83	3,86	3,48
″	″	″	526,0	″	″	″	″	2,49
4,3	″	1237,0	783,0	″	″	″	″	″
″	″	″	606,1	″	″	″	″	″

[Suite.]

Tableau n° IX. — *Propriétés mécaniques*

ESSENCE.	NUMÉRO de l'arbre.	QUANTITÉ d'eau.	DENSITÉ DES COUCHES.					VITESSE DU SON DAN		
			1.	2.	3.	4.	5.	1.	2.	3
Bouleau	39	37,83	0,783	0,751	0,795	0,787	0,797	11,33	11,52	12,0
		10,67	0,583	0,672	0,721	0,736	0,742	15,41	15,50	15,4
		9,02	0,580	0,670	0,742	0,747	0,710	14,91	15,92	14,6
Hêtre	41 (1)	19,46	0,785	0,745	0,751	0,712	"	9,04	9,13	10,6
		18,22	"	0,707	0,737	0,707	"	"	9,13	10,1
		13,94	0,730	0,729	0,716	0,708	"	9,73	9,65	11,2
		9,77	0,716	0,779	0,716	0,709	"	10,37	8,73	11,8
Hêtre	41 (3)	16,50	"	0,807	0,760	"	"	"	9,16	10,0
		15,69	0,663	0,798	0,708	"	"	9,06	10,48	11,5
		11,83	0,664	0,775	0,744	"	"	9,23	10,76	11,9
		7,63	"	0,782	0,696	"	"	"	10,84	11,7
Hêtre	46	22,41	"	0,784	0,695	0,672	"	"	10,43	10,0
		13,92	"	0,726	0,706	0,671	"	"	12,62	12,6
		11,49	"	0,748	0,753	0,691	"	"	12,95	12,1
		9,52	"	0,719	0,691	0,679	"	"	12,05	11,5
Frêne	57	31,50	0,635	0,742	"	"	"	13,05	13,30	"
		10,54	0,580	0,694	"	"	"	14,70	14,85	"
		8,61	0,555	0,617	"	"	"	14,02	14,74	"
Orme	58	33,26	0,601	0,670	0,709	0,741	"	9,08	10,53	12,5
		9,22	0,558	0,618	0,642	0,707	"	12,82	13,99	13,2
		9,17	0,546	0,562	0,650	0,653	"	12,30	13,24	14,4
Peuplier	64 (1)	22,73	0,345	0,300	0,360	0,288	"	11,65	12,00	11,7
		22,55	"	0,330	0,347	0,317	"	"	11,56	12,1
		17,21	0,390	0,334	0,300	0,339	"	12,44	12,42	12,5
		11,37	0,362	0,307	"	0,291	"	12,39	13,20	"
Peuplier	64 (3)	22,73	0,363	0,356	0,353	0,360	"	13,85	13,41	13,7
		22,55	"	"	0,369	0,378	"	"	"	12,6
		17,21	0,340	0,337	0,357	0,381	"	14,33	13,93	14,
		11,37	0,378	"	0,373	"	"	11,27	"	15,4
Acacia	66 (1)	18,43	0,623	0,691	0,723	0,803	"	14,10	14,24	14,4
		16,63	"	0,722	0,648	0,731	"	"	15,18	14,4

des fibres et à différents degrés d'humidité.

	ENT D'ÉLASTICITÉ DES COUCHES.			COHÉSION DES COUCHES PAR MILLIMÈTRE CARRÉ.				
	3.	4.	5.	1.	2.	3.	4.	5.
1,4	1298,7	1098,5	976,7	3.89	″	4,55	″	3,13
7,0	1926,9	1483,6	1234,4	7.03	7,48	7,01	4,14	3,15
2,4	1802,0	1583,7	1125,1	″	″	″	″	″
7,1	960,6	1067,9	″	″	″	″	″	″
2,5	841.6	1057,9	″	″	″	6,40	4,64	″
5,5	1013,3	1188,8	″	2,99	4,86	5,89	6,02	″
4,1	1122,6	1125,8	″	″	″	″	″	″
5,9	869,2	″	″	″	3,95	4.14	″	″
2,8	1070,0	″	″	″	″	″	″	″
3,7	1191,9	″	″	1,98	5,19	6,57	″	″
3,3	1092,4	″	″	″	″	″	″	″
9,3	732,9	748,8	″	″	″	″	″	″
1,7	1260,4	1147,0	″	″	5,61	3,60	3,57	″
1,3	1242,7	1175,8	″	″	8,20	5,41	5,11	″
4,1	1043,3	951,9	″	″	″	″	″	″
5,4	″	″	″	4.65	6,49	″	″	″
3,0	″	″	″	5.68	7,71	″	″	″
9,2	″	″	″	″	″	″	″	″
5,1	1248,7	1215,6	″	2,07	5,74	8,89	8,59	″
1,5	1273,9	1548,5	″	″	″	″	″	″
8,4	1530,2	1569,7	″	1,62	3,62	7,68	5,38	″
6,1	556,4	397,9	″	″	″	″	″	″
6,6	580,2	435,3	″	″	2,05	2,04	″	″
9,9	529,0	514,4	″	3,26	2,26	2,43	1,77	″
1,3	″	417,9	″	″	″	″	″	″
8,4	752,5	738,3	″	″	″	″	″	″
″	661,6	765,3	″	″	″	″	″	″
5,7	813,4	807,2	″	2,03	1.01	2,34	2,26	″
″	1005,6	″	″	″	″	″	″	″
7,0	1684,3	1703,0	[illegible]	″	″	″	″	″
1,6	1517,8	1539.8	″	″	8,67	8,92	9,15	″

[Suite.]

Tableau n° IX. — *Propriétés mécaniques*

ESSENCE.	NUMÉRO de l'arbre.	QUANTITÉ d'eau.	DENSITÉ DES COUCHES.					VITESSE DU SON DA		
			1.	2.	3.	4.	5.	1.	2.	3.
Acacia.......	66 (1)	15,66	0,617	0,684	0,691	0,753	"	14,09	14,32	14,4
		9,82	0,660	"	0,764	0,754	"	15,62	"	15,1
Acacia.......	66 (2)	18,43	0,712	0,717	0,674	0,695	"	14,52	15,64	14,6
		15,66	0,706	0,716	0,662	0,722	"	15,55	16,21	14,8
		9,82	0,638	0,725	0,654	0,723	"	16,43	16,66	15,9
Acacia.......	66 (3)	18,43	0,795	0,669	0,656	0,741	"	13,71	14,29	14,1
		15,66	0,677	0,680	0,675	0,709	"	13,71	14,77	14,0
Acacia.......	66 (4)	18,43	0,586	"	0,680	0,729	"	13,96	"	14,7
		15,66	0,603	"	0,703	0,726	"	14,29	"	14,7
		9,82	"	"	"	0,711	"	"	"	"
Sapin	18 (1)	21,87	0,558	0,405	0,500	0,496	0,508	10,33	14,57	15,5
		18,89	"	0,406	0,455	0,483	0,540	"	14,82	15,7
		16,28	0,435	0,449	0,510	0,517	0,526	11,03	15,48	16,2
		9,13	0,545	0,432	"	0,542	0,513	12,23	15,85	16,4
Sapin	18 (3)	18,65	0,603	0,473	0,488	0,492	0,458	10,94	13,49	15,6
		17,97	"	0,385	0,477	0,504	0,442	"	13,47	15,3
		15,98	0,487	0,455	0,493	0,506	0,480	11,32	13,81	16,0
		8,71	0,436	0,377	"	0,531	0,489	13,32	14,65	"
Sapin	18 (5)	19,84	"	0,410	0,474	0,462	"	"	13,40	15,0
		18,78	0,482	0,444	0,437	0,425	"	10,96	14,23	14,7
		14,51	0,480	0,468	0,493	0,464	"	11,31	14,61	14,9
		9,79	0,419	0,452	0,458	0,489	"	13,71	14,89	15,9
Sapin	65 (1)	20,20	"	0,503	0,448	0,464	0,519	"	10,07	11,8
		10,26	"	0,449	0,359	0,473	0,477	"	11,47	12,4
		7,27	"	0,406	0,406	0,416	0,366	"	12,16	14,0
Sapin	65 (2)	20,20	"	0,411	"	0,454	0,412	"	13,58	"
		10,26	"	0,400	"	0,433	0,464	"	14,32	"
		7,27	"	0,391	"	0,391	0,408	"	14,62	"
Sapin	65 (3)	20,20	"	0,384	0,385	0,481	0,473	"	13,36	12,4
		10,26	"	0,468	0,453	[illegible]462	0,439	"	14,14	13,1
		7,27	"	0,355	0,397	0,416	0,386	"	14,89	13,8

des fibres et à différents degrés d'humidité.

ENT D'ÉLASTICITÉ DES COUCHES.				COHÉSION DES COUCHES PAR MILLIMÈTRE CARRÉ.				
	3.	4.	5.	1.	2.	3.	4.	5.
,0	1644,1	1661,1	"	5,09	11,61	11,03	9,62	"
	1980,0	1486,0	"	"	"	"	"	"
,0	1634,0	1583,3	"	"	"	"	"	"
,0	1637,0	1601,3	"	4,43	10,19	10,30	9,85	"
,0	1887,0	2078,0	"	"	"	"	"	"
,0	1484,0	1650,0	"	"	"	"	"	"
,0	1503,0	1578,0	"	2,47	4,14	5,76	6,91	"
	1669,0	1717,0	"	"	"	"	"	"
	1726,0	1752,5	"	5,09	"	10,19	11,88	"
	"	2220,0	"	"	"	"	"	"
,8	1368,2	1167,1	1422,1	"	"	"	"	"
,9	1280,2	1233,6	1455,7	"	4,21	4,90	5,32	5,61
,0	1541,4	1311,1	1604,7	1,59	4,43	4,66	4,87	8,44
,7	1864,0	1359,6	1670,1	"	"	"	"	"
,4	1249,6	1318,3	1340,0	"	"	"	"	"
,2	1257,3	1317,7	1324,6	"	2,98	3,41	4,26	4,33
,9	1448,7	1471,3	1487,1	3,89	3,87	5,39	7,13	6,83
,0	"	1685,1	1695,3	"	"	"	"	"
,5	1207,2	1384,6	"	"	2,12	2,71	4,13	"
,8	1071,3	1217,2	"	"	"	"	"	"
,0	1236,8	1368,3	"	2,38	3,47	5,28	5,95	"
,3	1303,2	1534,6	"	"	"	"	"	"
,0	785,3	1184,0	1250,0	"	"	"	"	"
,8	630,2	1421,2	1498,9	"	1,11	1,83	2,93	4,06
,0	897,0	1337,0	1202,0	"	"	"	"	"
,5	"	1129,0	956,6	"	"	"	"	"
,1	"	1188,9	1555,6	"	3,12	"	2,62	"
,0	"	1165,0	1454,0	"	"	"	"	"
,4	669,2	1157,0	1253,0	"	"	"	"	"
,0	882,9	1276,7	1364,7	"	"	2,64	3,94	"
,0	861,0	1302,0	1285,0	"	"	"	"	"

[Suite.]

Tableau n° IX. — *Propriétés mécaniq*

ESSENCE.	NUMÉRO de l'arbre.	QUANTITÉ d'eau.	DENSITÉ DES COUCHES.					VITESSE DU SON D		
			1.	2	3.	4.	5.	1.	2.	3
Sapin	65 (4)	20,20	"	0,372	0,427	0,495	0,461	"	12,63	13,
		10,26	"	0,484	0,469	0,522	0,491	"	13,24	14,
		7,27	"	0,408	0,387	0,456	0,422	"	13,66	15,
Sapin	65 (5)	20,20	"	0,439	0,424	0,454	0,500	"	13,62	13,
		10,26	"	0,443	0,426	0,462	0,450	"	13,74	14,
		7,27	"	"	"	0,402	"	"	"	"
Sapin	65 (6)	20,20	0,454	0,391	0,437	0,473	0,465	9,80	13,94	14,
		10,26	0,442	0,390	0,402	0.451	0,458	10,09	14,09	15,
		7,27	0,413	0,362	0,353	0,392	0,458	11,14	14,92	15,
Pin	31 (1)	61,60	0,828	0,756	0,878	0,929	"	7,56	7,76	7,
		15,90	0,407	0,490	0,453	0,480	"	10,16	10,27	10,
		13,50	0,476	0,484	0,494	0,498	"	10,99	11,11	11,
		11,68	"	0,429	0,502	0,420	"	"	11,25	11,
		9,07	0,506	0,475	0,533	0,553	"	11,00	10,87	11,
Pin	31 (3)	14,63	"	0,410	0,446	"	"	"	12,26	12,
		14,07	0,421	0,479	0,469	"	"	8,47	11,56	11,
		9,96	0,506	0,466	0,497	"	"	10,24	11,66	12,
		9,77	0.499	0.439	0,439	"	"	8,94	12,25	12,

Nota. Pour le chéne 45 (pag. 98 et 99), on a mis les chiffres correspondants à la couche 6 au-dessous de c

des fibres et à différents degrés d'humidité.

ICIENT D'ÉLASTICITÉ DES COUCHES.				COHÉSION DES COUCHES PAR MILLIMÈTRE CARRÉ.				
2.	3.	4.	5.	1.	2.	3.	4.	5.
68,1	927,8	1206,0	1207,0	″	″	″	″	″
54,8	1167,1	1413,2	1446,6	″	″	3,37	″	4,57
57,0	1015,0	1344,0	1317,0	″	″	″	″	″
[illegible]	921,9	1081,0	1078,0	″	″	″	″	″
41,2	972,1	1016,2	1212,0	″	2,72	3,00	2,77	2,60
″	″	1059,0	″	″	″	″	″	″
54,7	1022,0	1093,0	1243,0	″	″	″	″	″
71,3	1019,3	1180,4	1306,3	1,16	2,95	2,43	3,35	4,26
06,0	926,0	1104,0	1359,0	″	″	″	″	″
07,8	571,4	640,6	″	″	″	″	″	″
67,8	601,9	689,8	″	″	″	″	″	″
85,8	745,1	814,0	″	1,54	1,69	2,56	2,74	″
10,7	726,0	692,3	″	″	2,68	4,08	3,42	″
2,6	799,8	975,8	″	″	″	″	″	″
86,6	767,9	″	″	″	2,81	2,84	″	″
6,0	635,9	″	″	″	″	″	″	″
14,8	861,6	″	″	″	″	″	″	″
5,7	739,5	″	″	1,44	1,63	1,83	″	″

Tableau n° X. — *Coefficients de la variation de la densité*

ESSENCE.	NUMÉRO de l'arbre.	COEFFICIENTS DE LA VARIATION DE LA DENSITÉ DANS LES COUCHES					
		1.	2.	3.	4.	5.	6.
Charme	7	0,00777	0,00709	"	"	"	"
Tremble	8	0,00316	"	0,00137	0,00237	"	"
Aune	12	0,00482	0,00378	0,00370	"	"	"
Sycomore....	22	0,00270	0,00464	0,00535	"	"	"
Érable	23	0,00465	0,00388	0,00235	"	"	"
Chêne.......	34 (1)	0,00484	0,00016	0,00455	"	"	"
Chêne.......	34 (3)	0,00598	0,00521	0,00599	0,00253	"	"
Chêne.......	45	0,00226	0,00462	0,00612	0,00450	0,00309	0,00485
Bouleau	39	0,00920	0,00380	0,00287	0,00207	0,00316	"
Hêtre	41 (1)	0,01088	0,00389	0,00662	0,00072	"	"
Hêtre	41 (3)	"	0,00498	0,00210	"	"	"
Hêtre	46	"	0.00645	0,00045	0,00017	"	"
Frêne.......	57	0.00481	0,00523	"	"	"	"
Orme	58	0,00339	0,00496	0,00369	0,00342	"	"
Peuplier.....	64 (1)	+0,00434	+0,00205	0,03019	+0,00092	"	"
Peuplier.....	64 (3)	0,00392	0,00967	+0,00499	"	"	"
Acacia	66 (1)	0,00348	0,00366	0,01598	0,01478	"	"
Acacia	66 (2)	0.00755	0.00050	0,00494	+0,00935	"	"
Acacia	66 (3)	0,05358	+0.00593	+0,00104	0,01559	"	"
Acacia	66 (4)	+0,01047	"	+0,01221	0,00218	"	"
Sapin	18 (1)	0,02063	+0.00883	0,03020	0,00879	+0,00942	"
Sapin.......	18 (3)	0,04995	0,01733	0,03315	+0,00931	+0,01240	"
Sapin.......	18 (5)	0.00775	+0.00733	0,07364	0,07556	"	"
Sapin.......	65 (1)	"	0,01285	0,01361	0,00800	0,01547	"
Sapin.......	65 (2)	"	0,00320	"	0,00769	0,00075	"
Sapin.......	65 (3)	"	0,00584	+0,01009	0,00721	0,01072	"
Sapin.......	65 (4)	"	+0,01888	0,00724	0,00609	0,00654	"
Sapin.......	65 (5)	"	+0,00092	+0,00047	0,00886	0,01006	"
Sapin.......	65 (6)	0,00482	0,00300	0,01146	0,00896	0,00133	"
Pin.........	31 (1)	0,00912	0,00773	0,00893	0,00972	"	"
Pin	31 (3)	"	0,01301	0,01488	"	"	"

son dans les couches, pour une perte de 1 *pour* 100 *d'humidité.*

COEFFICIENTS DE LA VARIATION DE LA VITESSE DU SON DANS LES COUCHES					MOYENNE.
2.	3.	4.	5.	6.	
0,00922	"	"	"	"	0,00951
0,00527	0,00778	0,00877	"	"	0,00803
0,00468	0,00641	"	"	"	0,00897
0,00433	0,00226	"	"	"	0,00540
0,00973	0,00818	"	"	"	0,00929
0,00808	0,00484	0,01118	0,00815	"	0,00805
0,00577	0,00008	0,00746	"	"	
0,00868	0,00626	0,00735	0,00882	0,00691	
0,01299	0,00892	0,00773	0,00540	"	0,00943
0,00290	0,01089	0,00686	"	"	0,01068
0,00559	0,00443	"	"	"	
0,01963	0,02074	0,01642	"	"	
0,00514	"	"	"	"	0,00489
0,01217	0,00451	0,00762	"	"	0,01006
0,00757	0,01236	0,00516	"	"	0,00592
0,00702	0,00846	0,00295	"	"	
0,00203	0,00364	0,00095	"	"	0,00576
0,01036	0,00679	0,00977	"	"	
0,01213	−0,00280	0,00026	"	"	
"	0,00000	0,00811	"	"	
0,00461	0,00612	0,00966	0,00266	"	0,00797
0,00876	0,00883	0,01029	0,00992	"	
0,00570	0,00685	0,00412	"	"	
0,01502	0,00976	0,00867	0,01224	"	
0,00570	"	0,00617	0,01942	"	
0,00736	0,00750	0,00906	0,00888	"	
0,00558	0,00739	0,00660	0,00664	"	
0,00089	0,00283	0,00398	0,00740	"	
0,00326	0,00480	0,00725	0,00374	"	
0,00817	0,01001	0,01086	"	"	0,01369
0,00799	0,02030	"	"	"	

Tableau n° XI. — *Contraction transvers*

ESSENCE.	NUMÉRO de l'arbre.	QUANTITÉ d'eau.	CÔTÉ moyen en millim.	CONTRACTION LINÉAIRE pour une perte de 1 p. 100 d'humidité.	
Charme.	7	37,22	6,84		
		11,01	6,51	0,00184	0,001
		8,95	6,62	0,00114	
Tremble.	8	38,56	7,22		
		21,83	6,74	0,00397	0,0038
		8,61	6,41	0,00374	
Aune.	12	28,55	6,95		
		16,03	6,65	0,00345	0,002
		9,25	6,66	0,00216	
Sycomore.	22	31,62	6,97		
		15,08	6,59	0,00329	0,0031
		10,71	6,54	0,00295	
Érable.	23	29,04	7,29		
		13,79	6,92	0,00333	0,0032
		8,75	6,81	0,00324	
Chêne.	34 (1)	19,08	7,07		
		17,40	7,02	0,00421	
		10,96	6,74	0,00575	0,004
		9,20	6,72	0,00501	
Chêne.	34 (3)	17,16	7,00		
		8,54	6,68	0,00530	0,005
Chêne.	45	44,83	11,10		
		19,53	10,00	0,00392	0,0035
		10,54	9,90	0,00315	
Bouleau.	39	37,83	7,25		
		10,67	6,58	0,00340	0,0034
		9,02	6,51	0,00354	

r suite de leur dessiccation.

s.	NUMÉRO de l'arbre.	QUANTITÉ d'eau.	CÔTÉ moyen en millim.	CONTRACTION LINÉAIRE pour une perte de 1 p. 100 d'humidité.	MOYENNES.	
....	41 (1)	19,46	6,96			
		13,94	6,84	0,00312	0,00393	0,00412
		9,77	6,64	0,00474		
....	41 (3)	16,50	6,82			
		11,83	6,75	0,00220	0,00201	
		7,63	6,71	0,00182		
....	46	22,41	7,23			
		13,92	6,82	0,00668	0,00641	
		11,49	6,67	0,00709		
		9,52	6,72	0,00547		
....	57	31,50	7,22			
		8,61	7,02	0,00121	0,00121	
....	58	33,26	7,12			
		9,22	6,64	0,00280	0,00294	
		9,17	6,59	0,00309		
....	64 (1) et (3)	22,73	7,07			
		17,21	6,78	0,00743	0,00583	
		11,37	6,73	0,00423		
....	66	18,43	4,87			
		15,66	4,85	0,00148	0,00300	
		9,82	4,68	0,00453		
....	18 (1)	21,87	7,13			
		18,89	7,12	0,00047	0,00509	0,00467
		16,28	6,86	0,00677		
		9,13	6,40	0,00804		
....	18 (3)	18,65	6,95			
		15,98	6,79	0,00862	0,00699	
		8,71	6,58	0,00536		
....	18 (5)	19,84	6,71			
		14,51	6,63	0,00224	0,00224	
....	65	20,20	10,62			
		10,26	10,16	0,00436	0,00436	
....	31 (3)	14,63	7,26			
		9,96	6,73	0,01563	0,01093	
		9,77	7,04	0,00623		

Moyenne générale pour toutes les essences..................... 0,00395

Tableau n° XIII. — *Nombre de couches annuelles comprises dans chacu*

ESSENCE.	NUMÉRO.	RAYON de la bille.	I.		
			NOMBRE DE COUCHES.	ÉPAISSEUR de l'anneau.	NOMBRE DE CO
		mm		mm	
Charme.....	7	126,5	Du centre à la 12e couche.	46,5	De la 12e à
Tremble....	8	110,7	Du centre à la 5e	28,7	De la 5e à
Aune........	12	101,1	Du centre à la 8e	16,5	De la 8e à
Sycomore...	22	108,2	Du centre à la 6e	20,0	De la 6e à
Érable......	23	95,4	Du centre à la 6e	22,5	De la 6e à
Chêne......	34 (1)	159,0	Du centre à la 10e	16,0	De la 10e à
Chêne......	34 (3)	125,0	Du centre à la 5e	9,0	De la 5e à
Bouleau.....	39	194,5	Du centre à la 6e	15,0	De la 6e à
Hêtre........	41 (1)	97,4	Du centre à la 7e	16,0	De la 7e à
Hêtre........	41 (3)	65,0	Du centre à la 6e	13,0	De la 6e à
Frêne........	57	81,1	Du centre à la 17e	36,0	De la 17e à
Orme........	58	77,2	Du centre à la 5e	13,2	De la 5e à
Peuplier....	64 (1)	178,5	Du centre à la 4e	28,5	De la 4e à
Peuplier....	64 (3)	120,0	Du centre à la 3e	16,0	De la 3e à
Sapin.......	18 (1)	144,5	Du centre à la 5e	19,5	De la 5e à
Sapin.......	18 (3)	117,0	Du centre à la 3e	7,5	De la 3e à
Sapin.......	18 (5)	89,8	Du centre à la 3e	11,0	De la 3e à
Pin..........	31 (1)	231,0	Du centre à la 9e	60,0	De la 9e à
Pin..........	31 (3)	122,0	Du centre à la 6e	26,5	De la 6e à

desquelles les tringles ont été prises, et épaisseur de ces anneaux.

3.		4.		5.	
couches.	Épaisseur de l'anneau.	Nombre des couches.	Épaisseur de l'anneau.	Nombre des couches.	Épaisseur de l'anneau.
	mm		mm		mm
la circonf.	30,5	″	″	″	″
la 24e	31,5	De la 24e à la circonf.	33,0	″	″
la circonf.	51,1	″	″	″	″
la circonf.	43,7	″	″	″	″
la circonf.	35,4	″	″	″	″
la 40e	34,5	De la 40e à la 65e	53,0	De la 65e à la circonf.	34,0
la 45e	51,0	De la 45e à la circonf.	37,5	″	″
la 58e	58,0	De la 58e à la 89e	36,0	De la 89e à la circonf.	41,5
la 30e	31,0	De la 30e à la circonf.	14,4	″	″
la circonf.	22,0	″	″	″	″
″	″	″	″	″	″
la 27e	29,0	De la 27e à la circonf.	17,0	″	″
la 26e	75,0	De la 26e à la circonf.	15,5	″	″
la 18e	42,0	De la 18e à la circonf.	14,0	″	″
la 52e	36,5	De la 52e à la 78e	32,0	De la 78e à la circonf.	13,5
la 40e	33,5	De la 40e à la 55e	20,5	De la 55e à la circouf.	19,0
la 28e	28,5	De la 28e à la circonf.	23,8	″	″
la 35e	58,5	De la 35e à la circonf.	22,0	″	″
la circonf	34,5	″	″	″	″

Tableau n° XIV. — *Expéri*

I

ESSENCE.	NUMÉRO de la bille.	LONGUEUR en mètres.	DIAMÈTRE en mètres.	POIDS ABSOLU en kilogrammes.	QUANTITÉ d'eau.	POIDS spécifiq
Hêtre.........	1	2,058	0,4113	258,90	38,30	0,94
Hêtre.........	6	2,031	0,2870	121,10	42,37	0,92
Hêtre.........	11	2,060	0,2427	93,40	43,17	0,98
Hêtre.........	27	2,033	0,2513	90,30	37,42	0,89
Hêtre.........	29	2,028	0,3695	192,70	39,43	0,88
Hêtre.........	32	2,036	0,4098	260,90	38,21	0,9
Hêtre.........	33	2,042	0,2284	74,80	39,88	0,89
Hêtre.........	41 (2)	2,061	0,1771	47,50	39,38	0,93
Hêtre.........	42	2,013	0,1432	28,00	33,46	0,86
Hêtre.........	44	2,058	0,1681	43,25	42,58	0,94
Hêtre.........	46 S.-E.	2,045	0,1969	57,20	34,35	0,91
Hêtre.........	N.-E.	2,054	0,1964	59,00	33,07	0,94
Hêtre.........	N.-O.	2,061	0,1960	58,60	34,87	0,94
Hêtre.........	49	2,039	0,1649	38,18	37,42	0,8
Hêtre.........	53	2,030	0,2456	94,20	39,10	0,9
Hêtre.........	55	2,066	0,2409	91,30	45,18	0,9
Hêtre.........	60	2,063	0,3111	138,10	37,15	0,8
Hêtre.........	62	2,075	0,2712	108,70	35,36	0,9
Chêne.........	2	2,077	0,2582	102,70	38,01	0,9
Chêne.........	3	2,036	0,2109	68,50	33,72	0,9
Chêne.........	4	2,066	0,2577	104,50	36,29	0,9
Chêne.........	5	2,054	0,2525	113,20	52,11	1,1
Chêne.........	9	2,088	0,2507	111,80	55,89	1,0
Chêne.........	10	2,065	0,1892	56,80	37,69	0,9
Chêne.........	26	2,009	0,1754	46,50	34,97	0,9
Chêne	30	2,024	0,3252	160,20	37,52	0,9
Chêne.........	34 (2)	2,077	0,2881	129,20	40,21	0,9
Chêne.........	34 (4)	2,055	0,1968	58,80	40,03	0,9
Chêne.........	35	2,025	0,1986	59,40	38,45	0,9
Chêne....... .	36	2,030	0,1119	18,56	34,23	0,9
Chêne.........	37	2,022	0,3547	182,90	41,70	0,9
Chêne.........	38	2,033	0,2499	111,40	53,75	1,1
Chêne	43	2,066	0,2790	128,70	37,11	1,0
Chêne.........	45 N.-O.	2,029	0,1220	24,60	44,64	1,0
Chêne.........	S.-E.	2,036	0,1224	24,70	40,69	1,0
Chêne.........	N.-E.	2,049	0,1222	23,90	41,72	0,9
Chêne........	S.-O.	2,019	0,1224	23,30	40,60	0,9
Chêne.........	48	2,053	0,1865	55,20	41,01	0,9

la flexion des billes entières.

4.

LÈCHES EN MILLIMÈTRES.		FLÈCHE CORRIGÉE en millimètres.	COEFFICIENT d'élasticité.	A 20 POUR 100 D'HUMIDITÉ.	
II.	Moyenne.			Poids spécifique.	Coefficient d'élasticité.
3,99	4,085	1,185	936,0	0,863	1218,7
7,72	7,925	5,439	737,3	0,821	1008,5
11,62	11,870	10,213	511,8	0,870	706,9
6,36	6,365	4,708	965,9	0,820	1243,7
5,19	4,895	1,995	853.6	0,802	1127,0
3,56	3,605	0,705	"	"	"
11,12	11,255	9,598	694,4	0,808	921,9
15,44	15,560	14,731	625,8	0,847	825,8
9,72	10,030	9,744	760,3	0,807	929,4
8,50	8,320	7,768	974,7	0,843	1336,8
20,69	20,815	19,020	687,3	0,855	850,4
23,90	23,895	22,100	597,6	0,888	726,8
25,01	24,925	23,130	575,6	0,874	717,1
".	8,810	8,258	990,2	0,803	1274,9
8,18	8,275	6,618	753,2	0,888	989,7
8,75	8,990	7,333	734,4	0,851	1037,8
8,38	8,550	5,650	599,7	0,807	769,6
7,63	7,845	5,359	908,5	0,839	1176,7
10,68	10,505	8,019	763,3	0,873	925,6
14,88	14,735	13,078	701,0	0,908	816,4
9,92	9,880	7,670	714,9	0,904	852,2
10.40	10,395	8,185	726,9	0,953	996,4
11,16	11,145	8,935	685,1	0,921	964,3
10,57	11,280	9,899	1191,6	0,905	1439,6
11,59	11,875	11,099	810,2	0,897	953,3
6,24	6,110	3,210	884,1	0,883	1066,3
8,28	8,520	6,034	654,5	0,873	809,7
14,58	14,645	13,264	759,6	0,861	938,2
11,16	11,085	9,980	778,8	0,873	946,9
24,29	23,345	23,059	861,6	0,874	1006,4
5,85	5,865	2,965	676,3	0,832	848,1
14,22	14,210	12,000	516,7	0,959	716,0
7.62	7,850	5,364	837,1	0,946	1006,3
18,02	17,930	17,654	772,9	0,930	898,2
18,83	19,225	18,949	710,7	0,941	960,9
19,87	19,705	19,429	697,7	0,903	875,9
22,68	21,945	21,669	621,5	0,896	882,6
10,40	10,685	9,856	760,5	0,897	948,3

[Suite.] **Tableau n° XIV. — *Expéri***

ESSENCE.	NUMÉRO de la bille.	LONGUEUR en mètres.	DIAMÈTRE en mètres.	POIDS ABSOLU en kilogrammes.	QUANTITÉ d'eau.	POIDS spécifiq
Chêne.........	52	2,066	0,1725	43,19	35,03	0,89
Chêne.........	56	2,042	0,1931	53,10	42,46	0,88
Chêne.........	59	2,071	0,2244	77,80	37,83	0,96
Chêne.........	61	2,082	0,2225	75,10	35,40	0,92
Charme.......	7	2,045	0,2530	107,40	52,07	1,04
Charme.......	40	2,064	0,1966	53,30	30,37	0,85
Tremble.......	8	2,057	0,2214	57,80	37,07	0,73
Aune.........	12	2,077	0,2023	53,00	54,46	0,79
Sycomore.....	22	2,040	0,2165	63,10	38,98	0,84
Érable........	23	2,071	0,1909	47,10	38,21	0,79
Bouleau.......	25	2,057	0,2060	61,80	42,89	0,90
Bouleau.......	39	2,061	0,3890	227,30	34,05	0,92
Frêne.........	57	2,075	0,2361	31,125	26,79	0,72
Orme..........	58	2,066	0,1545	31,44	36,30	0,81
Acacia........	63 (1)	2,090	0,1006	12,625	24,99	0,76
Acacia........	63 (2)	2,117	0,0856	8,90	24,26	0,73
Peuplier.......	64 (2)	2,053	0,2559	70,30	39,38	0,66
Peuplier.......	64 (4)	2,068	0,1755	33,88	39,38	0,67
Sapin.........	16	2,054	0,4409	196,90	36,46	0,62
Sapin.........	17	2,025	0,3447	112,20	42,11	0,59
Sapin.........	18 (2)	2,083	0,2584	68,70	39,93	0,62
Sapin.........	18 (4)	2,101	0,2169	45,20	34,92	0,58
Sapin.........	18 (6)	2,064	0,1688	31,94	49,62	0,69
Sapin.........	19	2,047	0,1408	24,25	38,78	0,76
Sapin.........	20	2,037	0,2798	99,70	48,47	0,79
Sapin.........	21	2,065	0,2812	99,00	45,07	0,77
Sapin.........	24	2,033	0,3120	122,90	35,85	0,79
Sapin.........	28	2,021	0,3239	90,10	32,72	0,54
Sapin.........	47	2,040	0,1754	41,75	48,23	0,84
Sapin.........	51	2,041	0,1622	66,10	52,57	0,74
Pin...........	13	2,050	0,2328	62,60	40,65	0,71
Pin...........	14	2,045	0,2968	111,10	42,31	0,78
Pin...........	15	2,030	0,3106	134,30	49,74	0,87
Pin...........	31 (2)	2,073	0,3253	149,30	45,44	0,84
Pin...........	31 (4)	2,037	0,1861	43,30	51,58	0,78
Pin...........	50	2,094	0,1805	275,50	42,29	0,6
Pin...........	54	2,040	0,2771	102,70	48,16	0,8

flexion des billes entières.

; EN MILLIMÈTRES.		FLÈCHE CORRIGÉE en millimètres.	COEFFICIENT d'élasticité.	A 20 POUR 100 D'HUMIDITÉ.	
II.	Moyenne.			Poids spécifique.	Coefficient d'élasticité.
16,76	16,205	15,376	666,1	0,838	784,7
10,34	9,915	8,534	1273,9	0,804	1608,8
12,52	12,690	11,033	648,3	0,879	784,2
10,06	10,995	9,338	792,5	0,868	936,5
10,98	10,995	8,785	671,9	0,796	871,6
10,34	10,380	8,999	1124,3	0,785	1252,5
13,99	14,115	12,458	605,9	0,701	752,6
10,81	10,625	9,520	758,3	0,683	1115,9
"	9,840	8,183	1008,8	0,773	1127,8
8,94	9,165	8,336	819,1	0,742	1045,7
11,03	11,005	9,900	678,2	0,814	905,7
4,48	4,520	1,620	855,7	0,873	1032,3
9,66	9,615	9,063	963,8	0,701	993,8
11,69	11,390	10,838	979,0	0,761	1242,9
4,97	4,960	4,909	1109,3	0,739	1141,4
11,10	10,585	10,534	986,2	0,713	1010,7
"	8,900	8,071	262,0	0,608	297,2
re.	"	"	"	0,618	"
7,12	7,265	4,365	192,4	0,522	203,9
12,45	12,565	9,665	232,6	0,458	248,3
13,95	13,745	11,259	542,0	0,499	578,0
7,19	7,440	6,059	1127,1	0,492	1193,7
14,94	14,855	14,026	796,4	0,480	844,4
16,31	16,860	16,574	478,0	0,613	509,1
9,69	9,885	7,399	599,9	0,562	637,3
10,18	10,025	7,539	577,1	0,571	615,4
9,86	9,775	6,875	487,2	0,661	516,7
17,55	17,260	14,360	200,8	0,470	211,6
13,92	13,830	13,001	738,7	0,600	785,2
12,54	12,395	10,738	543,6	0,491	572,2
Rupture.	36,200	33,990	242,2	0,561	311,6
13,92	13,750	10,850	377,0	0,600	491,1
12,47	12,125	9,225	369,7	0,599	502,0
15,03	14,970	12,070	234,8	0,634	312,2
t fendillé.	"	"	"	0,521	"
5,26	5,150	2,250	227,7	0,515	296,6
21,96	21,825	19,339	238,6	0,586	321,8

Tableau n° XV. — *Densité, coefficient réel d'élasticité, vitess*

ESSENCE.	NUMÉRO DE L'ARBRE.	HAUTEUR DE LA SECTION TRANSVERSALE AU-DESSUS DU SOL EN MÈTRES.	DANS LE SENS DU RAYON DE L'ARBRE.									
			POIDS ABSOLU.	POIDS SPÉCIFIQUE.	LONGUEUR.	LARGEUR.	ÉPAISSEUR.	NOMBRE de vibrations transversales doubles dans le sens		COEFFICIENT d'élasticité dans le sens		MOYENNE.
								de la largeur.	de l'épaisseur.	de la largeur.	de l'épaisseur.	
			gr		mm	mm	mm					
Charme...	7	Base.	10,35	0,775	128,0	10,580	9,860	1164,0	1040,7	217,0	199,8	208,4
Tremble..	8	1,96	7,20	0,419	130,0	10,665	9,842	948,2	859,1	109,6	105,7	107,6
Aune.	12	5,50	6.54	0,575	107,0	10,681	9,946	1347,4	1207,5	102,2	94,5	98,3
Sycomore.	22	1,50	7,00	0,672	99,0	10,741	9,803	1706,7	1542,2	136,2	133,5	134,8
Érable....	23	3,00	8.48	0,695	117,5	10,686	9,678	1219,1	1122,8	154,4	159,7	157,1
Chêne. ...	34	Base.	14,45	0,847	173,0	10,331	9,547	656,4	595,3	262,4	252,7	257,5
Chêne. ..	»	4,05	12,80	0,906	138,0	10,376	9,861	655,7	649,7	138,4	122,2	130,3
Chêne....	»	8,12	9,13	0,830	108,0	10,265	9,922	1406,6	1333,3	181,6	174,7	178,1
Bouleau ..	39	Base.	23,99	0.836	318,0	10,327	9,703	119,1	107,9	82,5	79,6	81,1
Hêtre.....	41	Base.	13,80	0,820	165,0	10,565	9,651	766,5	688,2	292,3	282,4	287,3
Hêtre.....	»	3,60	8,00	0,814	99,7	10,380	9,496	1969,2	1828,6	264,4	272,4	268,4
Hêtre.....	»	5,70	6,77	0,817	83,0	10,446	9,559	2844,5	2509,8	262,6	244,1	253,3
Frêne... .	57	1,35	5,86	0,700	76,0	10,804	10,194	2782,6	2461,6	118,05	104,1	111,3
Orme.....	58	1,35	5,60	0,699	79,0	10,522	9,641	2509,8	2245,6	125,6	119,7	122,6
Peuplier..	64	Base.	11,74	0,352	302,0	10,722	10,298	196,9	186,9	93,5	91,2	92,3
Peuplier..	»	4,75	5,41	0,359	138,0	10,799	10,119	775,8	761,9	63,5	69,8	66,6
Peuplier..	»	8,84	3,56	0,390	86,0	10,885	9,754	1910,5	1684,2	62,1	60,1	61,1
Sapin.....	18	Base.	11,49	0,615	179,0	10,402	10,038	520,3	467,2	141,8	122,7	132,3
Sapin.....	»	7,32	5,86	0,477	118,0	10,421	9,980	1049,2	864,8	84,2	62,4	73,3
Sapin......	»	14,48	8,92	0,517	120,0	10,478	13,729	1066,7	1049,2	99,7	56,2	77,9
Pin.......	31	Base.	13,59	0,522	260,0	10,155	9,857	966,8	906,8	144,5	153,3	148,9
Pin.......	»	(*a*)	6,55	0,547	120,1	10,009	9,961	917,6	888,9	85,7	79,5	82,6
Pin.......	»	(*b*)	5,95	0,485	120,1	9,832	10,366	1084,7	1113,0	107,8	101,7	104,7
Pin.......	»	4,12	5,70	0,522	100,4	10.642	10,228	1506,0	1391,3	93,1	86,0	89,5
Pin.......	»	8,20	3,75	0,435	80,0	10,740	10,029	1939,4	1939,4	50,9	58,4	54,6
Acacia....			3,35	0,766	65,4	8,284	8,558	3200,0	3368,5	167,1	173,5	170,3
Acacia....			»	»	»	»	»	»	»	»	»	»

vant deux lignes perpendiculaires à la direction des fibres.

DANS LE SENS DE LA TANGENTE AUX COUCHES ANNUELLES.

LONGUEUR.	LARGEUR.	ÉPAISSEUR.	NOMBRE de vibrations transversales doubles dans le sens		COEFFICIENT d'élasticité dans le sens		MOYENNE.	VITESSE DU SON.	COHÉSION.
			de la largeur.	de l'épaisseur.	de la largeur.	de l'épaisseur.			
mm 295,0	mm 10,597	mm 9,938	306,2	297,0	113,2	93,6	103,4	3,60	0,608
196,0	10,642	10,224	252,5	256,0	41,4	46,1	43,7	2,74	0,414
174.0	10,606	10,217	379,8	362.6	59,9	58,9	59.4	3,14	0,175
183,0	10,529	9.968	365,7	354,6	78,6	82,5	80,5	3,42	0,610
166.0	10,642	10,124	408,9	410.3	68,9	76,6	72,7	3,12	0,371
360,0	10,283	9,935	109,7	106,4	137,2	137,0	137,1	3,90	0,480
221,0	10,270	10,200	271.8	250,5	114,1	98.3	106,2	3,68	0,344
158,0	10,294	10,119	584,5	551,7	139,3	128,2	146,2	4,04	0,423
231,0	10,408	9,397	299,2	271,1	154,7	135,8	155,2	4,57	1,063
261,0	10,677	10,052	227,4	223,0	154,0	167,2	160,6	4,22	0,969
171,0	10,528	9,949	528,9	518,2	156,6	168,2	162,4	4,26	0,611
166,5	10,438	10.206	731,4	695,7	159,1	150,5	154.8	4,31	0,676
116,0	10,578	10,204	1032,3	964,6	103,2	100,9	102,0	3,80	0,408
196,0	10.702	9,953	699,4	666,7	61,8	65,0	63,4	3,03	0,366
376,0	10,831	9,214	92,3	90.1	40,2	59,1	49,6	3,77	0,222
231,0	11,034	10,745	»	»	»	»	»	»	0,202
143,0	10,969	10,380	457,1	457,1	26,7	29,8	28,2	2,55	0,219
265,0	10,459	10,176	105,7	99,1	37,2	34,6	35,9	2,34	0,413
297,0	10,773	10,803	165,2	172,3	18,7	21,4	20,1	1,98	0,124
188,0	10,659	10,352	290,9	271,2	48,2	44,4	46,3	2,75	0,353
365,0	10,243	9,804	56,7	55,8	30,6	32,4	31.5	2,48	0,230
»	»	»	»	»	»	»	»	»	»
»	»	»	»	»	»	»	»	»	»
145,0	9,901	9,827	374,3	376,5	25,4	26,1	25,7	2,33	0,184
»	»	»	»	»	»	»	»	»	»
98,4	8,103	8,472	1319,6	1354,5	164,8	158,8	161,8	4,16	1,092
119,5	8,187	8,467	864,9	876,7	145,5	139,8	142,6	3,98	1,370

Tableau n° XVI. — INFLUENCE DE LA HAUTEUR. — *Rapports*

ESSENCE.	NUMÉRO DE LA BILLE.	HAUTEUR à laquelle la bille a été coupée.	MARCHE DES PROPRIÉTÉS MÉCANIQUES DANS TOUTE LA MASSE D A DIFFÉRENTES HAUTEURS ET DANS DIFFÉRENTES DIRECTI											
			POIDS SPÉCIFIQUE				COEFFICIENT D'ÉLASTICITÉ dans le sens				COHÉSION dans le sens			des
							des fibres							
			moyen dans le sens des fibres.	de la bille entière.	dans le sens du rayon.	dans le sens de la tangente.	d'après l'allongement.	d'après la flexion.	du rayon.	de la tangente.	des fibres.	du rayon.	de la tangente.	Rayon.
		m												
Charme ...	7	3,00	0,687	»	0,775	0,783	966,3	871,6	208,4	103,4	2,99	1,007	0,608	0,21
Tremble ..	8	1,96	0,504	»	0,419	0,537	1399,8	752,6	107,6	43,7	7,20	0,171	0,414	0,07
Aune......	12	5,50	0,514	»	0,575	0,600	1100,4	1115,9	98,3	59,4	4,54	0,329	0,175	0,08
Sycomore.	22	1,50	0,611	»	0,672	0,694	1199,0	1127,8	134,9	80,3	6,16	0,522	0,610	0,11
Érable	23	3,00	0,607	»	0,695	0,689	997,1	1045,7	157,1	72,7	3,58	0,716	0,371	0,15
Chêne.....	34 (1)	Base.	0,719	»	0,847	0,863	1287,2	»	257,5	137,1	7,41	0,608	0,450	0,29
Chêne.....	34 (2)	2,00	»	0,873	»	»	»	809,7	»	»	»	»	»	»
Chêne.....	34 (3)	4,05	0,697	»	0,906	0,797	994,6	»	130,3	106,2	5,33	0,509	0,344	0,13
Chêne.....	34 (4)	8,12	»	0,861	0,830	0,808	»	938,2	178,2	146,2	»	0,629	0,423	0,19
Bouleau...	39	3,00	0,749	»	0,836	0,801	1145,3	1032,3	81,1	155,2	4,30	0,823	1,063	0,07
Hêtre	41 (1)	Base.	0,742	»	0,820	0,802	837,4	»	237,3	160,6	5,25	1,216	0,969	0,33
Hêtre	41 (2)	3,60	»	0,847	0,814	0,794	»	825,8	268,4	162,4	»	0,649	0,611	0,32
Hêtre	41 (3)	5,70	0,735	»	0,817	0,770	682,8	»	253,3	154,8	3,23	0,791	0,676	0,37
Frêne . . .	57	1,35	0,694	»	0,700	0,783	1249,0	993,8	111,3	102,0	6,78	0,218	0,408	0,08
Orme	58	1,35	0,685	»	0,699	0,709	1087,7	1242,9	122,6	63,4	6,99	0,345	0,366	0,11
Peuplier ..	64 (1)	Base.	0,324	»	0,352	0,326	554,2	»	92,3	49,6	2,13	0,165	0,222	0,16
Peuplier ..	64 (2)	4,75	»	0,608	0,359	0,349	»	297,2	66,6	»	»	0,128	0,202	0,22
Peuplier ..	64 (3)	8,84	0,357	»	0,390	0,388	705,8	»	61,1	28,2	1,82	»	0,219	0,08
Acacia	63 (1)	0,65	»	0,739	»	»	»	1141,4	»	»	»	»	»	»
Acacia	63 (2)	3,36	»	0,713	»	»	»	1010,7	»	»	»	»	»	»
Acacia	66 (1)	Base.	0,765	»	»	»	1406,8	»	»	»	6,12	»	»	»
Acacia	66 (2)	2,10	0,690	»	»	»	1341,2	»	»	»	9,71	»	»	»
Acacia	66 (3)	4,20	0,712	»	»	»	1329,9	»	»	»	5,75	»	»	»
Acacia	66 (4)	6,30	0,681	»	»	»	1341,5	»	»	»	10,13	»	»	»
Sapin......	18 (1)	Base.	0,479	»	0,615	0,615	1098,6	»	132,3	35,9	4,89	0,219	0,413	0,12
Sapin......	18 (2)	3,50	»	0,499	»	»	»	578,0	»	»	»	»	»	»
Sapin......	18 (3)	7,32	0,474	»	0,477	0,484	1206,8	»	73,3	20,1	2,81	0,135	0,124	0,06
Sapin....	18 (4)	10,20	»	0,492	»	»	»	1193,7	»	»	»	»	»	»
Sapin......	18 (5)	14,48	0,463	»	0,517	0,577	1197,0	»	77,9	46,3	3,19	0,306	0,353	0,08
Sapin......	18 (6)	18,00	»	0,481	»	»	»	844,4	»	»	»	»	»	»
Sapin.....	65 (1)	Base.	0,486	»	»	»	1009,1	»	»	»	2,90	»	»	»
Sapin.....	65 (2)	2,00	0,428	»	»	»	956,2	»	»	»	2,80	»	»	»
Sapin	65 (3)	4,00	0,446	»	»	»	995,0	»	»	»	3,40	»	»	»
Sapin....	65 (4)	6,00	0,453	»	»	»	1039,3	»	»	»	4,08	»	»	»
Sapin.....	65 (5)	8,00	0,463	»	»	»	983,0	»	»	»	2,75	»	»	»
Sapin......	65 (6)	10,00	0,452	»	»	»	1028,1	»	»	»	3,36	»	»	»
Pin.	31 (1)	Base.	0,502	»	0,522	0,503	533,7	»	148,9	31,5	2,21	0,399	0,239	0,27
Pin	31 (2)	2,06	»	0,634	»	»	»	312,2	»	»	»	»	»	»
Pin	31 (3)	4,12	0,512	»	0,522	0,458	594,5	»	89,5	25,7	2,76	0,322	0.154	0,13
Pin	31 (4)	6,16	»	0,521	»	»	»	»	»	»	»	»	»	»
Pin	31 (5)	8,20	»	»	0,435	»	»	»	54,6	»	»	0,046	»	»

et des cohésions suivant trois directions perpendiculaires.

[illegible] PROPRIÉTÉS MÉCANIQUES DANS UNE MÊME COUCHE LIGNEUSE A DIFFÉRENTES HAUTEURS.

[illegible] SPÉCIFIQUE.			COEFFICIENT D'ÉLASTICITÉ				COHÉSION.			
	b.	*a.*	*d.*	*c.*	*b.*	*a.*	*d.*	*c.*	*b.*	*a.*
»	»	»	»	»	»	»	»	»	»	»
»	»	»	»	»	»	»	»	»	»	»
»	»	»	»	»	»	»	»	»	»	»
»	»	»	»	»	»	»	»	»	»	»
»	»	»	»	»	»	»	»	»	»	»
[illegible]	0,806	0,887	1102,8	1778,7	1397,5	1005,3	5,04	6,92	8,90	6,86
»	»	»	»	»	»	»	»	»	»	»
[illegible]	0,751	0,646	1070,0	1122,5	1041,8	936,2	2,23	5,33	6,20	4,68
»	»	»	»	»	»	»	»	»	»	»
»	»	»	»	»	»	»	»	»	»	»
[illegible]	0,712	»	687,6	897,7	998,4	»	4,21	6,64	4,24	»
»	»	»	»	»	»	»	»	»	»	»
[illegible]	0,663	»	568,0	716,8	739,0	»	1,11	3,35	3,24	»
»	»	»	»	»	»	»	»	»	»	»
»	»	»	»	»	»	»	»	»	»	»
[illegible]	0,313	»	553,4	569,4	472,7	»	2,15	2,21	1,64	»
»	»	»	»	»	»	»	»	»	»	»
[illegible]	0,370	»	751,1	697,0	736,7	»	1,88	0,94	2,10	»
»	»	»	»	»	»	»	»	»	»	»
»	»	»	»	»	»	»	»	»	»	»
[illegible]	0,881	»	1323,9	1443,4	1447,8	»	4,61	5,36	7,82	»
»	»	»	»	»	»	»	»	»	»	»
»	»	»	»	»	»	»	»	»	»	»
[illegible]	0,731	»	1030,3	1201,4	1423,9	»	5,09	7,64	11,88	»
[illegible]	0,486	0,538	853,2	1165,5	1061,5	1286,6	3,59	5,01	5,54	4,91
»	»	»	»	»	»	»	»	»	»	»
[illegible]	0,485	0,447	837,5	937,6	1273,6	1232,5	1,87	2,41	2,48	3,15
»	»	»	»	»	»	»	»	»	»	»
»	0,405	0,468	»	»	786,0	1363,7	»	»	2,08	4,08
»	»	»	»	»	»	»	»	»	»	»
[illegible]	0,466	0,518	576,9	683,4	1142,3	1228,1	1,11	1,83	2,98	4,06
»	»	»	»	»	»	»	»	»	»	»
[illegible]	0,387	0,481	»	742,1	641,3	1102,4	»	»	2,64	3,94
»	»	»	»	»	»	»	»	»	»	»
»	0,439	0,424	»	»	872,0	872,1	»	»	2,72	3,00
»	0,454	»	»	»	466,9	»	»	»	1,18	»
[illegible]	0,521	»	509,8	534,6	617,9	»	1,69	2,56	2,74	»
»	»	»	»	»	»	»	»	»	»	»
[illegible]	0,510	»	209,7	658,7	570,1	»	1,44	2,81	2,84	»
»	»	»	»	»	»	»	»	»	»	»
»	»	»	»	»	»	»	»	»	»	»

Tableau n° XVII. — *Expéri*

DÉSIGNATION DES PIÈCES.	NUMÉRO.	DISTANCE des appuis.	LONGUEUR en mètres.	LARGEUR en millim.	ÉPAISSEUR en millim.	POIDS absolu en kilogr.	POIDS spécifique	[illegible] en kilogr
Chevron ou trafté...	1	m 2,500	4,000	78,2	80,4	19,1	0,759	0 35 75 115 155 215 0 255 315 355 415 515 515 565 625 665 735
Chevron ou trafté...	2	3,000	4,010	82,8	81,4	17,2	0,636	0 35 65 115 0 115 165 215 0 215 265 315 0 300 350 400 0 400 450 500 540
Pièce de 5 à 6, dite *simple panne*..	3	5,500	6,536	136,7	161,0	141,7	0,985	0 2225 3325
Pièce de 6 à 7, dite *simple panne*..	4	5,500	6,820	159,9	189,0	191,3	0,928	0 1725 1925 3125 3725 4125 0 55[illegible] 0 5525

rce en chéne.

FLÈCHE élastique en millim.	FLÈCHE MOYENNE pour une charge de 100 kilogrammes en millimètres.		COEFFICIENT d'élasticité.	COHÉSION.	OBSERVATIONS.
4,20	12,000	12,412	774,3	5,60	
9,42	12,560				
14,86	12,922				
19,79	12,768				
26,16	12,167				
"	"				
31,02	12,165				
39,14	12,425				
43,01	12,116				
50,79	12,239				
65,71	12,759				
					*Après avoir été soumis à la même charge pendant douze heures.
					Rupture subite.
8,56	24,457	25,139	601,3	4,60	
20,17	31,031				
27,85	24,217				
"	"				
26,05	22,600				
41,16	24,946				
49,86	23,194				
"	"				
51,86	24,121				
"	"				
75,71	24,035				
"	"				
75,97	25,323				
"	"				
105,04	26,260				
"	"				
105,39	26,347				
254,26	11,425	11,425	638,1	5,71	La rupture s'est opérée à 50 centimètres de distance du milieu dans un endroit rempli de nœuds.
69,80	4,046	3,826	1007,0	10,55	
73,24	3,810				
"	"				
"	"				
144,08	3,493				* La rupture s'est faite très-lentement, après que la charge de 5525 kilogrammes avait été portée pendant plus d'une demi-heure; de longues fentes longitudinales s'étaient d'abord formées, puis la rupture a eu lieu à 25 centimètres du milieu de la pièce
"	"				
218,56	3,955				

[Suite.]

Tableau nº XVII. — *Expéri*

DÉSIGNATION DES PIÈCES.	NUMÉRO.	DISTANCE des appuis.	LONGUEUR en mètres.	LARGEUR en millim.	ÉPAISSEUR en millim.	POIDS absolu en kilogr.	POIDS spécifique
Pièce de 7 à 8, dite *panne*........	5	m 5,500	6,103	182,1	209,7	220,0	0,944
Pièce de 7 à 8, dite *panne*........	6	5,500	7,062	190,7	220,0	273,2	0,922
Pièce de 8 à 9, dite *panne*	8	5,500	6,110	216,7	236,7	300,3	0,958
Pièce de 8 ½ à 9 ½, dite *panne*........	7	5,500	5,870	231,8	252,8	346,7	1,008
Planche ou échantillon....	10	3,000	3,652	143,4	42,2	18,2	0,824

ences en chêne.

ions cor-gée illim.	FLÈCHE élastique en millim.	FLÈCHE MOYENNE pour une charge de 100 kilogrammes en millimètres.		COEFFICIENT d'élasticité.	COHÉSION.	OBSERVATIONS.
					2,68	Rupture dans un endroit défectueux.
,00						
,04	66,62	2,445	2,385	858,9	4,90	
,42	″	″				
,07	″	″				* La pièce était restée sans charge pendant vingt-quatre heures.
,11	65,04	2,387				
,74	73,67	2,284				
,08	85,01	2,282				
,90	106,83	2,528				
,33						
,75						Rupture subite.
,00						
,65	39,86	1,791	1,760	822,3	5,11	
,79	″	″				
,51	39,72	1,785				
,10	46,31	1,699				
,39	52,60	1,739				
,52	53,73	1,776				* Cette même charge était restée suspendue pendant plus de deux heures.
,07	63,28	1,699				
,60	82,81	1,830				
,52						
,98						* Sous l'action de ce poids, l'arbre a commencé à se fendre longitudinalement, et sous les poids suivants, il a filé lentement avant de se casser.
,77						
,53						
,00						
,11	51,21	1,305	1,346	825,1	4,60	
,90	″	″				
3,06	52,16	1,329				
3,41	77,51	1,403				
5,24						
,11						
,78						Rupture subite au milieu sans fente longitudinale.
,00						
7,38	17,38	49,657	51,735	1210,7	6,99	
9,32	29,32	53,309				
9,18	39,18	52,240				
1,61						
3,52						
5,14						
5,13						

[Suite.] Tableau n° XVII. — *Expéri*

DÉSIGNATION DES PIÈCES.	NUMÉRO.	DISTANCE des appuis.	LONGUEUR en mètres.	LARGEUR en millim.	ÉPAISSEUR en millim.	POIDS absolu en kilogr.	POIDS spécifique	CHA en kilog
Planche ou **échantillon** ...	10	m 3,000	3,652	143,4	42,2	18,2	0,824	175 195 215 255 295 375
Planche ou entrevous.....	9	3,000	3,371	242,2	28,2	16,4	0,712	0 35 55 75 0 75 95 115 0 135 155 175 0 195 215 255 335 335
Madrier ou doublette	11	5,500	6,500	293,4	54,6	71,3	0,685	0 35 55 75 95 115 0 115 135 165 0 185 215 0 235 265 315 0 315 [illegible] 4

merce en chêne.

ÈCHE de corrigée millim.	FLÈCHE élastique en millim.	FLÈCHE MOYENNE pour une charge de 100 kilogrammes en millimètres.		COEFFICIENT d'élasticité.	COHÉSION.	OBSERVATIONS.
3,76						
6,82						
7,17						
2,05						
2,91						
ture.						
0,00						
4,85	34,85	99,571	99,322	1251,2	10,43	
5,35	55,35	100,637				
3,69	72,48	96,640				
1,21	″	″				
3,73	72,52	96,693				
5,79	94,58	99,558				
5,77	113,88	99,026				
1,89	″	″				
7,16	135,27	100,200				
9,37	″	″				
0,65	174,83	99,903				
5,82	″	″				
4,08	198,26	101,672				
8,87						
8,13						
9,43						
1,43						
ture.						
0,00						
1,42	31,42	89,772	90,228	965,3	4,83	
0,75	50,75	92,273				
8,31	68,31	91,080				
6,50	86,50	91,053				
2,97	101,10	87,913				
1,87	″	″				
3,52	101,65	88,391				
3,96	″	″				
1,93	147,85	89,606				
4,08	″	″				
0,78	166,70	90,108				
8,31	192,62	89,591				
5,69	″	″				
7,89	212,20	90,298				
5,39	″	″				
5,13	287,39	91,235				
7,74	″	″				
5,71	287,97	91,419				
9,87						
pture.						Rupture subite.

Tableau n° XVIII. — *Exp*

DÉSIGNATION DES PIÈCES.	NUMÉRO.	DISTANCE des appuis.	LONGUEUR en mètres.	LARGEUR en millim.	ÉPAISSEUR en millim.	POIDS absolu en kilogr.	POIDS spécifique
Chevron	2	m 9,000	10,360	87,8	115,0	50,75	0,485
Chevron	6	9,000	10,560	93,7	130,1	58,45	0,454
Chevron	8	9,000	10,500	96,5	124,1	63,25	0,503
Pièce de 6 à 7, dite *simple panne*.	9	9,000	10,410	164,0	194,5	169,50	0,510

nerce en sapin.

[illegible]	FLÈCHE élastique en millim.	FLÈCHE MOYENNE pour une charge de 100 kilogrammes en millimètres.		COEFFICIENT d'élasticité.	COHÉSION.	OBSERVATIONS.
0,00						
3,96	92,69	117,366	122,341	1115,6	5,45	
1,27	"	"				
6,24	143,48	122,632				
2,76	"	"				
7,08	206,87	123,874				
0,21	"	"				
4,14	272,32	125,493				
1,82	"	"				
2,83	424,27	133,839				
8,56						
						Rupture subite.
0,00						
77,75	76,57	65,445	69,419	1272,4	4,82	
1,18	"	"				
58,83	155,29	71,562				
3,54	"	"				
32,03	225,86	71,249				
6,17						
14,38						
0,00						
83,82	82,64	70,632	71,355	1384,8	6,19	
1,18	"	"				
22,04	118,99	71,252				
3,05	"	"				
56,87	153,68	70,820				
3,19	"	"				
32,56	227,80	71,861				
4,76	"	"				
07,48	300,90	72,158				
6,58	"	"				
61,74	348,84	73,132				
12,90						
						Rupture lente.
0,00						
20,07						
09,67	102,19	10,090	10,506	1437,5	5,84	
27,55	"	"				
02,48	187,07	10,922				
35,84						
						Rupture lente.

[Suite.] Tableau n° XVIII. — *Exp*

DÉSIGNATION DES PIÈCES.	NUMÉRO.	DISTANCE des appuis.	LONGUEUR en mètres.	LARGEUR en millim.	ÉPAISSEUR en millim.	POIDS absolu en kilogr.	POIDS spécifique
Pièce de 6 à 7, dite *simple panne*.	5	m 9,000	10,490	169,2	196,1	171,00	0,491
Pièce de 6 à 7, dite *simple panne*..	1	9,000	10,470	176,5	198,4	210,00	0,573
Pièce de 8 à 9, dite *panne*........	3	9,000	10,470	220,2	245,5	304,00	0,537
Pièce de 8 à 9, dite *panne*........	4	9,000	10,420	223,4	240,4	347,00	0,620
Pièce de 8 à 9, dite *panne*........	10	9,000	10,540	225,5	243,0	281,25	0,487
Pièce de 9 à 10, dite *panne*........	11	11,000	13,000	254,6	283,5	475,00	0,506
Pièce de 11 à 12, dite *recharge*.....	7	13,000	14,000	289,9	324,1	697,00	0,530

erce en sapin.

èches s cor- gée illim.	FLÈCHE élastique en millim.	FLÈCHE MOYENNE pour une charge de 100 kilogrammes en millimètres.		COEFFICIENT d'élasticité.	COHÉSION.	OBSERVATIONS
,00						
,95						
,59	127,88	12,626				
,66	"	"	13,570	1052,6	4,35	
,75	249,63	14,514				
,07						
						Rupture subite.
					3,76	La rupture a été instantanée, ce qui doit faire supposer que cette première charge a déjà été un peu trop forte.
0,00						
5,36	92,80	5,380	5,380	1039,7	3,71	
2,56						
						Rupture lente.
7,71	97,43	5,648				
0,28	"	"	5,794	1013,5	3,39	
9,66	144,08	5,941				
5,58						
						Rupture lente.
0,00						
6,05	95,59	5,481	5,481	1027,6	4,34	
0,46						
0,00						
3,89	83,90	4,811				
0,01	"	"				
8,29	161,67	4,984	4,959	1156,7	4,69	
6,62	"	"				
6,59	215,62	5,081				
0,97						
						Rupture subite.
0,00						
4,70	80,69	4,627				
4,01	"	"				
4,75	130,74	5,139				
2,07	162,93	4,872	4,896	1136,7	4,55	
9,14	"	"				
5,41	189,15	4,796				
6,26	"	"				
5,34	249,54	5,047				
5,80						
12,96						Rupture subite avec éclats au milieu de la pièce dans un endroit sans défaut.

[Suite.] Tableau nº XVIII. — *Expéri*

DÉSIGNATION DES PIÈCES.	NUMÉRO.	DISTANCE des appuis.	LONGUEUR en mètres.	LARGEUR en millim.	ÉPAISSEUR en millim.	POIDS absolu en kilogr.	POIDS spécifique	en kilog
Madrier............	12	3,02	4,235	249,8	57,0	33,47	0,555	0 57 0 117 0 217 0 317 0 417 0 517 0 617 0 717 977
Planche............	13	3,02	4,240	242,2	27,7	15,70	0,552	0 37 0 57 0 77 0 97 0 117 0 137 0 157 0 197

erce en sapin.

cor- te llim.	FLÈCHE élastique en millim.	FLÈCHE MOYENNE pour une charge de 100 kilogrammes en millimètres.		COEFFICIENT d'élasticité.	COHÉSION.	OBSERVATIONS.
,00						
,80	7,80	13,684	13,658	1089,8	5,63	
,00	"	"				
,95	15,84	13,538				
,11	"	"				
,02	28,58	13,170				
,44	"	"				
,16	43,45	13,707				
,71	"	"				
,10	57,66	13,827				
,44	"	"				
,28	71,50	13,830				
,78	"	"				
,14	85,47	13,852				
,67						
,55						
ure.						Rupture subite.
,00						
,14	42,00	113,514	111,261	1202,2	5,20	
,14	"	"				
,86	64,58	113,298				
,28	"	"				
,67	86,34	112,130				
,33	"	"				
,20	104,44	107,670				
,76	"	"				
,28	127,04	108,581				
,24	"	"				
,05	152,52	111,328				
,53	"	"				
,88	176,32	112,306				
,56						Rupture subite dans un nœud placé à quelques centimètres du milieu de la planche.
ture.						

Tableau n° XIX. — *Influen*

NATURE DU TERRAIN.	EXPOSITION.	AGE.	DENSITÉ.
CHÊNE A GLANDS SESSILES.			
Sol sec et peu fertile.			
Grès vosgien, sec...........	Sud.	51 ans.	0,897
Grès vosgien, sec...........	Crête de la montagne.	60 ans.	0,897
Grès bigarré, sec...........	Sud.	78 ans.	0,873
Sol fertile et assez frais.			
Grès vosgien................	Ouest.	50 ans.	0,874
Grès bigarré................	Est.	74 ans.	0,953
Grès vosgien................	Ouest.	85 ans.	0,873
Grès vosgien................	Ouest.	95 ans.	0,867
Grès vosgien................	Ouest.	105 ans.	0,832
Grès vosgien................	Ouest.	164 ans.	0,917
Grès vosgien................	Nord.	103 ans.	0,883
Sol fangeux et plat.			
Grès bigarré................	"	40 ans.	0,905
Grès vosgien................	"	75 ans.	0,838
CHÊNE A GLANDS PÉDONCULÉS.			
Sol sec et peu fertile.			
Muschelkalk, sec............	Sud.	73 ans.	0,804
Grès bigarré, sec...........	Sud.	74 ans.	0,908
Sol fertile et assez frais.			
Muschelkalk.................	Est.	74 ans.	0,868
Grès bigarré................	Est.	78 ans.	0,904
Sol fangeux et plat.			
Grès bigarré................	"	71 ans.	0,921
Muschelkalk.................	"	78 ans.	0,879

ion et du terrain.

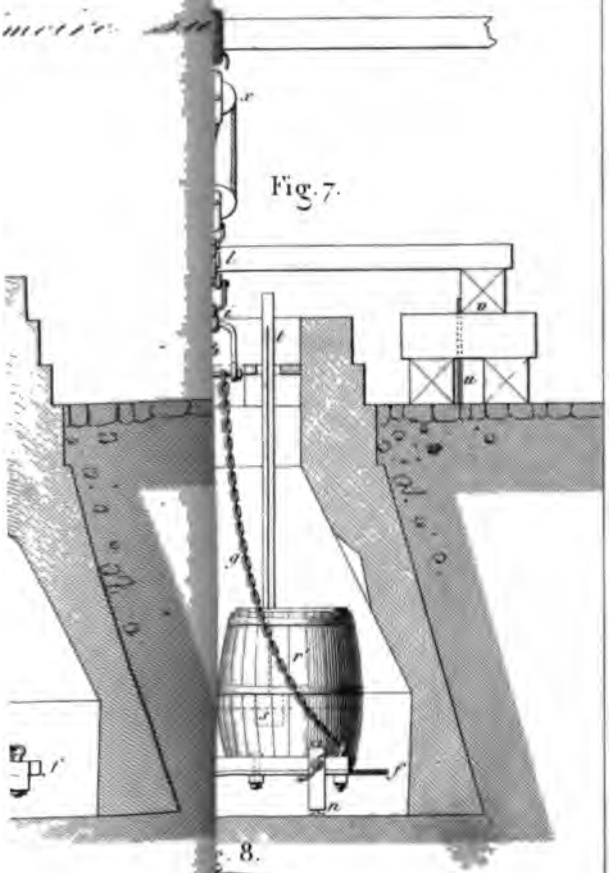
DU TERRAIN.	EXPOSITION.	AGE.	DENSITÉ.	COEFFICIENT d'élasticité.
	HÊTRE.			
	Sol sec et peu fertile.			
, sec	Sud.	51 ans.	0,803	1274,9
, sec	Crête de la montagne.	72 ans.	0,820	1243,7
, sec	Sud.	72 ans.	0,863	1218,7
, sec	Sud.	62 ans.	0,851	1037,8
, un peu sec.....	Est.	68 ans.	0,839	1176,7
	Sol fertile et assez frais.			
....	Ouest.	50 ans.	0,847	825,8
....	Ouest.	51 ans.	0,808	921,9
....	Ouest.	60 ans.	0,807	929,4
....	Ouest.	95 ans.	0,872	764,8
....	Nord.	90 ans.	0,802	1137,0
....	Nord-est.	69 ans.	0,821	1008,5
	Sol fangeux et plat.			
....	"	85 ans	0,888	989,7
....	"	69 ans.	0,870	706,9
....	"	76 ans.	0,807	769,6

SAPIN (Grès vosgien).

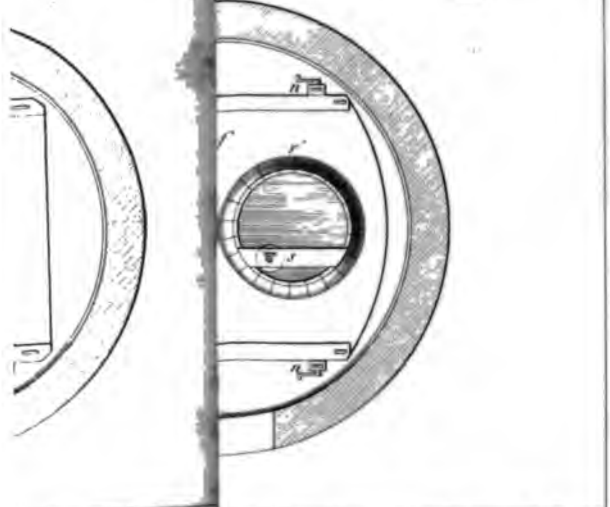
PIÈCE.	TERRAIN SEC AU SUD.			TERRAIN FERTILE AU NORD.			TERRAIN FERTILE AU NORD-OUEST (mais un peu sec).		
	Densité.	Coefficient d'élastic.	Cohésion.	Densité.	Coefficient d'élastic.	Cohésion	Densité.	Coefficient d'élastic.	Cohésion.
......	0,485	1115,6	5,45	0,454	1272,4	4,82	0,503	1384,8	6,19
7...	0,573	"	3,76	0,491	1052,6	4,35	0,510	1437,5	5,84
9...	0,537	1039,7	3,71	0,620	1013,5	3,39	0,487	1027,6	4,34
10...	"	"	"	"	"	"	0,506	1156,7	4,69
12...		"	"	"	"	"	0,530	1136,7	4,55

Pl. I.

Fig. 7.



g. 8.



Gravé par E. Wormser

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ON A NEW TYPE OF STEAM ENGINE, THEORETICALLY CAPABLE OF UTILIZING THE FULL MECHANICAL EQUIVALENT OF HEAT-ENERGY, AND ON SOME POINTS IN THEORY INDICATING ITS PRACTICABILITY.

Presented at the Nashville meeting of the American Association for the Advancement of Science, 1877.

By Prof. ROBERT H. THURSTON, Vice-President.

I.—It is easy to show that the existing common type of steam engine, even if perfect as a piece of mechanism, necessarily wastes a very large proportion of the heat-energy which is supplied to it, and that no possible improvement short of a complete change of type can greatly increase the efficiency of the best modern engine.

A steam engine, theoretically capable of fully utilizing the heat-energy supplied, and of delivering the mechanical equivalent of that heat, has never yet been constructed. The possibility of constructing such an engine has been denied by both physicists and engineers. Nevertheless, theoretically perfect air and gas engines have been designed and built, and a steam engine can probably be made, which may fully utilize all heat not lost by conduction, radiation, and friction. The object of the present paper is to show, not only the possibility of designing such an engine, using steam as the working fluid, but also the probable practicability of constructing a machine which shall waste no heat, except by conduction and radiation, and no power except by friction, under conditions which the engineer will admit to be attainable.

The theory of the proposed new type of engine is perfectly simple; and its construction, although involving the overcoming of grave difficulties in the reduction of losses by friction to a satisfactory extent, may possibly prove no more difficult a problem, than have been many others already solved.

The working fluid is assumed to be steam, because the proposed type of engine cannot be adapted for use with the permanent gases without special and undesirable modifications.

II.—A very simple conception, originating with Sadi Carnot, who published it in his well known work on Heat, half a century ago,[1] has furnished a basis upon which has been established the test of a perfect heat-engine. In applying this test, it is necessary to follow the operation of the engine through a complete cycle. The cycle embraces a succession of changes, which concludes by the return of the system to the precise set of conditions with which the cycle commenced. Such a cycle is a *closed curve of conditions.* It is only possible to infer the real relation existing between the heat-energy imparted to any machine and the mechanical energy developed from it after the working fluid, used as a conveyor of the heat-energy in that machine, has been restored, after experiencing a complete cycle of changes, to its primitive condition. The heat-cycle usually corresponds to a kinematic cycle in the engine itself.

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[1] *Reflexions sur la Puissance du Feu*; Paris, 1824.

During each complete cycle, a certain amount of heat-energy is supplied to the machine, and a certain other amount of mechanical work is done by the machine upon external objects and upon its own moving parts. The result is the accomplishment of a certain amount of useful work, and the consumption, or, more properly, the conversion, of a definite amount of heat in doing that work. Let these two quantities be called A and A'.

Imagine the engine reversed and to complete a cycle in the opposite direction. If the engine be "perfect," every operation is, during this inverted cycle, given a negative direction, and the net result is the re-conversion of the heat A', from the equivalent mechanical energy, A, which is expended in driving the engine backward. An engine capable of reversion in this manner, and with such a result, is a perfect engine and yields the greatest possible amount of mechanical energy from the heat supplied to it.

For, if not, suppose it coupled to an engine which is more nearly perfect, *i. e.*, requires less heat to do a given amount of work. Then suppose the first driven backward by the second. The former restores heat to the source from which the latter receives it. The amount restored is the full mechanical equivalent of the work expended in reversing the assumed imperfect engine. But the heat required by the more perfect machine, which does that work, is less than that amount, and it consequently follows that there must be an accumulation of heat in the reservoir, which heat must have been the product of actual creation—a *reductio ad absurdum.* It follows, therefore, that the reversible engine is a perfect heat-engine, and will yield the full mechanical equivalent of all heat which it is theoretically capable of utilizing.

It follows from the principle of the "conservation of energy," that if a certain quantity of energy is communicated to a system at the commencement of, or during, a cycle, no part of that energy can be extinguished. It must all reappear during the cycle in some form, before the completion of the cycle. In the heat engine there is no known way in which heat-energy can be expended, except by the production of mechanical energy, by loss in friction, and by dispersion by conduction and radiation from the system. In all heat engines, any heat not disposed of in these ways will reappear in its original form of heat-motion.

A perfect engine, therefore, in the sense in which the term is here used, is one in which no heat is lost by conduction, radiation or friction, and in which all heat not discharged unused at the completion of the cycle is utilized by conversion into mechanical energy which may be usefully applied.

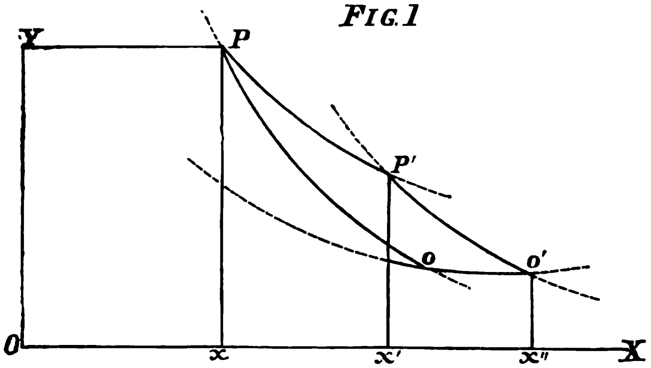
Assuming those conditions which are known to be invariable where the permanent or perfect gases are used as working fluids, to be equally invariable with all working fluids, it is easy to determine, by the application of the principle of Carnot, what is the efficiency of a perfect engine working under any given set of conditions as to temperature. Carnot's conception was, to a certain extent, faulty, in consequence of the fact that, in his time, the character of heat-motion was not understood, the doctrine of the persistence of energy had not been taught, and the science of thermo-dynamics had not taken shape. Sir Wm. Thomson, in 1849, modified the conception of Carnot in accordance with the now well known laws of thermo dynamics, and gave us the perfect test of the perfect engine.

III.—In illustration, conceive a working cylinder and piston, made of some absolutely non-conducting material. Let the variation of pressure and volume of the working fluid in this cylinder during a single cycle—a double stroke of the piston—on one side of the piston be represented in the accompanying diagram, as in the indicator diagram obtained by Watt from actual steam engines at the end of the 18th century, and as in the theoretical diagrams given by Clapeyron, in 1834. This is such a diagram as would be produced by a pencil moving horizontally with the piston, and at the same time having a vertical motion, proportional to the magnitude of the pressure of the working fluid within the cylinder.

Thus, in the figure, the length of the stroke of piston is measure on the diagram by the distance from the abscissa of the point P that of the point o'. The pressure varies from that correspondin to the ordinate of P to that of o'. The area of the figure, $P P' o'$ is a measure of work done.

Suppose the cylinder to contain a certain volume, $O x$, of an pansible fluid at the pressure $P x$. Let it expand, driving the pis before it and doing work against a varying resistance. Supply the fluid a quantity of heat, just sufficient to compensate the loss transformation into mechanical work. The fluid is thus retaine the original temperature, and the curve of varying pressure wil

FIG.1



an isothermal curve. From the point P' let the fluid expand wit receiving heat from any source; it will now lose heat by transfor tion into work, and its temperature will fall, the line becoming adiabatic curve, as such a curve has been named by Rankine. o', reverse the motion of the piston, and remove the heat due to compression of the working fluid as rapidly as that heat is produ The pressure line now becomes o' o, and is an isothermal cu Let the removal of the heat of compression cease at the point which point is so situated that the final return of the piston to starting point will bring the pressure line, now again adiabatic, to and thus restore the fluid to its original condition, as to both tem ature and pressure.

Such a cycle can evidently be reversed, each operation occurr in reverse order, and in the reverse direction, and any engine of wh this is a representative cycle, is a perfect engine.

IV.—Carnot showed that the maximum efficiency—the maximum oportion of heat utilized to heat supplied—in the perfect gas gine, when the engine transfers heat from a source having an abso- ;e temperature, t, and discharges unutilized heat at a lower absolute nperature, t', is a fraction equal to the ratio of the range of tem- rature to the maximum temperature :—

$$E=\frac{t-t'}{t}.$$

Benjamin Thompson, Count Rumford, in 1798, indicated the true ure of heat, and by experiment obtained an approximate measure its mechanical equivalent, which was corrected by the later experi- nts of Joule, 1843 to 1849. Sir Wm. Thomson, in 1848, showed t we have an absolute measure of temperature (and of heat also, re no physical change of state occurs) in a scale of which the is situated 493·2° Fahr., or 274° Centigrade, below the ting point of ice under atmospheric pressure. In any fluid, no nge occurring in its capacity for heat with change of temperature, quantity of heat present in the mass is proportional to its abso- temperature. The mechanical equivalent of heat is now univer- y taken as 772 foot-pounds of energy per British thermal unit, as 424 kilogrammetres per metric thermal unit, or *calorie*. These s furnish us with a means of determining the theoretical efficiency ngines of perfect types working under specified conditions. All ting heat engines are imperfect in proportion as they waste rgy by the conduction and radiation of heat to external bodies, as they waste mechanical energy by friction; since, on reversal, energy lost in these directions cannot be gathered up by the hine and restored to the source. The heat engine is also, in a tain sense, imperfect, because it is usually the fact that heat cted unutilized is all lost, and cannot be restored to the source m whence it was supplied to the engine. In some forms of heat gines, a part of this rejected heat is so restored.

V.—Whenever, as is the case with steam, a working fluid experi- ces a change of its physical state, which results in a change of its ecific heat while in the engine and doing work, such estimates efficiency become only approximate. To secure an accurate easure of efficiency, it is necessary, if Thomson's absolute scale temperatures is retained, to construct a special thermometer for each substance, on which the degree must have a different magnitude for each as measured by the ordinary thermometer.

Carnot's unqualified statement, is not, therefore, correct. It is not true that the efficiency of a heat engine is simply "a function of the two limits of temperature between which the engine works, and not of the nature of the substance employed." This is only true when the specific heat remains constant between those limits, and down to the absolute zero. As the specific heat is not always thus constant, it is a matter of importance to consider the nature of the substance used as a working fluid in any case.

When such changes of physical state occur after the working fluid is rejected, they have no importance, except, as will be seen presently, so far as they have a bearing upon the effect of modifying the type of engine.

VI.—Applying the principles which have now been stated to the determination of the maximum possible efficiency of the most perfect of existing steam engines, and comparing the result with the efficiency actually attained, it is easy to determine to what extent improvement is possible without change of type.

Heat engines may be divided, for present purposes, into three principal classes, according to their disposition of rejected heat:

1. Those which restore all heat rejected from the working cylinder to the reservoir from which it was derived.

2. Those which restore a part of the unutilized heat of the working fluid, discharging the remainder from the system and allowing it to be wasted.

3. Those which waste all heat rejected from the working cylinder.

No existing type of steam engine belongs to the first of the classes specified. Some forms of air and gas engines are theoretically assignable to that class, as, by means of some form of "regenerator," they store up rejected heat and restore it to the succeeding charge of working fluid as it enters the cylinder. Actually, however, these engines cannot perform this part of their task thoroughly, and they are thus really to be catalogued in the second class.

Nearly all heat engines, including the steam engine, are most correctly assignable to the third class. In the steam engine, the rejected heat, on leaving the steam cylinder, is thrown into the condenser or discharged into the atmosphere, and, in either case, is wasted. A small portion is usually saved by supplying the boiler n the hot-well or from heaters in which it has acquired some ease of temperature by transfer from exhausted steam. In so far his takes place, they fall into class 2. They will here be consid- l as belonging to class 3.

.ll actual steam engines may therefore be considered as belonging ne primary class. They all take steam from a source having a high perature, degrade the heat thus obtained to a lower temperature, g work and consuming a definite amount of heat in the produc- of a definite amount of mechanical energy, and finally discharge tilized heat into the atmosphere or into a large volume of conden- water, by which it is carried out of the system and thrown away.

II. The steam engine differs radically from air and gas engines of wn class in one respect; and this difference, although passed over pparently unimportant by accepted authorities on the theory of the m engine, has constituted a serious and hitherto unsurmounted culty in the process of calculation of the exact efficiency of the m engine.

ith all heat engines in which the working fluid experiences no ge of physical state, as, for example, in the air and gas engines, ave

$$\frac{t-t'}{t}=\frac{Q-Q'}{Q},$$

quantities of heat being proportional to the temperatures on absolute scale. The same is approximately, if not absolutely, of superheated and of dry steam. It is true, with sufficient tness for the purposes of the engineer, of water. The proportion t retained, however, in the fluid which actuates the steam engine mixture of steam and water in which the proportions of the two s are difficult of determination, if not absolutely indeterminate, at commencement of the stroke, and in which the proportions are tantly changing throughout the stroke of the piston.

he varying specific heat of the mixture, and the variation in the unt of work done, might be more satisfactorily estimated were it for the peculiar methods of waste of heat which are charac- tic of the steam engine, the most important of which are the rnal condensation and re-evaporation, which will be more fully ribed presently.

ssuming, however, for the moment, that the steam cylinder is e, as in the typical engine of Carnot, of non-conducting materials, a given amount of steam, entering it at a temperature and volume such that the work done before expansion commences is equal to $p\ v$, is permitted to expand normally, the curve of pressures following, approximately, a line nearly hyperbolic.

As the specific heat of saturated steam is negative, a portion of the charge is gradually condensed as expansion goes on and work is done, and there is finally discharged from the cylinder a mixture of steam and water, the water bearing a higher proportion to the steam remaining as the work of expansion is greater.

But this mixture of liquid and vapor contains, usually, vastly less heat than an equal weight of steam at the same temperature. In any gas engine, $t : t' = Q : Q'$; but here the proportion does not hold, and we have, for steam,

$$\frac{Q-Q'}{Q} > \frac{t-t'}{t}.$$

Hence, the steam-engine *should be* more economical than the air or gas-engine working between the same limits of temperature. That it is not, can only be due to the cause of loss already adverted to as peculiar to the steam engine; or, more correctly, to heat engines, in which the working fluid changes its physical state within the working limits of temperature and pressure. In consequence of the facts just stated, it is seen that the usually accepted method of estimating economy, as in gas engines, is not correct as applied to the steam engine.

VIII.—Neglecting the inaccuracy arising from the peculiar action of steam in the engine, as just described, we will make an approximate determination of the maximum efficiency of the perfect steam engine of the best existing type, and working between the widest limits of temperature generally and successfully attained.

A marine compound engine of the most successful type in general use, takes steam from the boiler at a pressure of 90 pounds per square inch above a vacuum, and discharges the exhaust steam into a condenser having a temperature of 126° Fahr. (53° Cent.), and at a pressure of about 2 pounds per square inch. The original temperature of the boiler steam was 320° Fahr. (160° Cent.) The efficiency should then be:

$$\frac{320-126}{781\cdot2} = \frac{160-53}{434} = 0\cdot25 +.$$

should do 772 × 0·25 = 193 foot-pounds of work for each British
rmal unit of heat supplied to it. Per hour and per horse-power
1,980,000 foot-pounds, it would demand about 10,000 heat units,
ich would be supplied by the combustion of a pound of coal,
porating 10 pounds of steam—a very usual and a very good rate
evaporation for steam boilers. Could all of the heat supplied to
engine be fully utilized, however, it would do its work with one-
rth of this consumption of fuel—on 2½ pounds of steam per hour
l per horse-power, using ¼ pound of coal. But even this estimated
ciency does not represent the full theoretical economy of an ideal
am engine, since, in consequence of the fact already adverted to,
t the specific heat of the mingled steam and water, which forms
working fluid, is continually changing as expansion proceeds;
l, therefore, the real efficiency is greater than here estimated.
is difference becomes very great with great expansion. We may,
refore, say that the perfect steam engine, working under the
umed conditions, would work on considerably less than 1 pound
coal per hour and per horse-power.

he average performance of the best engines built to-day, to work
ugh the assumed range of temperature and pressure, does not
approximate to the calculated efficiency of the perfect engine.
latest and best type of compound engine, taking steam from the
er at 75 pounds pressure by gauge, and exhausting its steam at a
perature approximating that assumed in the above calculations,
ires, usually, about 20 pounds of steam, or, say, 2 pounds of coal
hour and per horse-power. Good engines as now built, therefore,
e at least one-half the heat which is theoretically *available* for
production of power in the existing type of steam engine.

X.—Now, attempting to apply the test of Carnot and Thomson,
may detect the defects of the machine, and learn what are the
es of loss of all this wasted power:

racing the operations which constitute the cycle of the machine
everse order and direction, we find that such an inverted cycle
t include the collection and restoration of all that heat-energy
h has been discharged into the atmosphere or into the condensing
r at the end of the stroke of the piston; the collection and
oration of all heat which has been lost by radiation and conduc-
to surrounding bodies; and the reconversion into available heat
ll work lost in friction. All this is manifestly impossible in the

existing type of engine, and it is equally evident that the methods o reducing these losses—which are, to a certain extent, inevitable—b friction, and by conduction and radiation, are well known, and ar applicable to engines of every conceivable type.

The sources of loss are, then:

1. Friction.
2. Conduction and radiation of heat.
3. The rejection of unutilized heat in the exhaust steam.

The first two of these methods of loss are comparatively unimportant, and, by proper management, can be reduced to a very insignificant amount. It is the last named cause of loss of work that is to be studied, with a view to the determination of some method of greatly increasing the efficiency of the steam engine.

X.—The rejected heat which is exhausted from the engine at the end of each stroke, consists of two parts:

1. That which, in the example above given, constitutes about three-fourths of the heat supplied, and which, in consequence of the natural distribution of the heat throughout the scale of temperature, is necessarily always lost in this type of engine.

2. That which, by the operation known as condensation and re-evaporation in the steam cylinder, is transferred from the steam chest to the exhaust side, at each stroke, without doing its share of the work of the engine.

The method of the first loss of heat has already been indicated with sufficient clearness. The second loss occurs in a way which has but recently become well understood, and which is still not clearly comprehended by many even professional engineers. It is, however, easily explained.

When steam expands in the steam cylinder, it enters at a comparatively high temperature, and at the end of the stroke, at the lowered pressure, has a considerably decreased temperature. There is therefore a tendency, which sometimes has a marked effect, to produce similar changes in the temperature of the cylinder itself—heating it at the entrance of the steam, and cooling it as expansion progresses. The greater the expansion, the greater is this variation of temperature. With considerable expansion, it becomes very great, and, the metal of the cylinder being affected to some depth, amount of heat passing back and forth between the steam and metal is often a very large proportion of the total heat of the entering steam. When, therefore, saturated steam enters the cylinder, it finds the interior surface of the metal comparatively cool, its temperature having been reduced by contact with the exhaust steam just rejected from it. Condensation, therefore, occurs and continues until a sufficient amount of heat has been transferred from the entering steam to the metal of the cylinder, to restore it to the temperature of the prime steam. Thus it is invariably the fact, when superheating is not practiced, that·the steam cylinder, at the instant of closing the steam valve, contains both steam and water. The relative amount of the two fluids varies greatly, but it is usually found, where considerable expansion is adopted, that the weight of water is quite great. After the closing of the induction valve, and as expansion progresses, the water, originally at the temperature of its boiling point, under boiler pressure and that of the entering steam, finds itself under a constantly decreasing pressure. Re-evaporation, commencing with the first decrement of pressure, goes on regularly, until the expansion is brought to an end by the termination of the stroke of piston and the opening of the exhaust valve. During this re-evaporation, the water can only obtain its latent heat of evaporation by robbing the surrounding metallic surfaces, after absorbing from the supernatant steam any slight excess of temperature above that due its pressure, which the latter may have itself taken from the metal of the cylinder during that period of rapidly decreasing temperature and pressure which immediately succeeded the commencement of the expansion. Finally, at the opening of the exhaust valve, a sudden drop of pressure occurs, and the whole mass of mingled steam and water remaining in the cylinder at once expands into the condenser, or into the atmosphere, and the re-evaporation of water, which now occurs in great quantity, makes another draft upon the cylinder, reducing its interior to, approximately, the temperature of the condenser or of the boiling point, under atmospheric pressure. Thus heat is taken into the metal of the cylinder from the "live" steam at the beginning of the stroke, and transferred to the exhaust steam, and thrown away without conversion into work. The heat absorbed in re-evaporation before the exhaust takes place, is partly utilized; but that which is taken up at the opening of the exhaust valve, is wholly wasted.

The process of waste just described is one of the most serious causes of loss of heat in the modern steam engine; in some cases, the loss from this cause exceeds that due to the unavoidable rejection of heat at the lower limit of temperature, which only is taken into account in all accepted theoretical estimates of efficiency. It is this method of waste that prevents the engineer acquiring even an approximation to the estimated gain due to considerable expansion. It is this which places a limit to our expansion of steam, which limit has, as yet, been but little altered by any of the expedients which have been adopted to extend it. It has been found by experience that with steam of 60 or 70 pounds pressure, no gain in efficiency can usually be secured by expanding more than five or six times. Passing this limit, the losses due the wasteful transfer of heat to the exhaust steam increase much more rapidly than the gain due to the increased conversion of heat into work by expansion.[1] The higher the steam pressure and the greater the speed of piston, the less the loss from the operation of this cause. The use of superheated steam also reduces it. When the steam is so far superheated that the mass taken into the cylinder may surrender to the metal all the heat required to warm it up to the temperature due the steam pressure, without itself falling to the temperature of saturation at that pressure, this loss is reduced to a minimum. But the saving is effected at the sacrifice of some theoretical efficiency. Steam jacketing produces its well known benefit by checking the waste due to this condensation and re-evaporation.

The losses by the rejection of heat from the engine without transformation are thus seen to be due to two entirely different causes: the first, which is always a proportion, $\frac{Q'}{Q} \times U$, of the total heat supplied, can evidently only be saved by some radical change of type of engine. The second, which has been diminished, but has never been wholly checked by known expedients, seems very probably to require equally radical treatment to effect its cure. It is perfect evident, nevertheless, that to secure any great increase in the efficiency of heat engines in which steam is to be used as the working fluid, some change must be made by which these losses must be avoided; it is only then by a change of type that the now usual loss of nearly three-fourths the heat by rejection at the lower limit of temperature, and of a very large fraction of the remaining energy, can be, to any considerable extent, prevented. Could a change of type be secured by which all this heat could be utilized, giving a theoretical efficiency of unity, we might expect an actual efficiency of at least one-half, and thus obtain a horse-power by the expenditure of five pounds of steam, and the combustion of a half pound of coal per hour. The best existing type of engine has been seen to demand four times this amount, and it is very common for engines to require ten times as much.[1]

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[1] In general, the number of times which the volume of steam may be expanded in the high-pressure engine with maximum economy, is not far from $\frac{1}{2}\sqrt{P}$, where P is the pressure in pounds per square inch; it rarely exceeds $0{\cdot}75\sqrt{P}$.

XI.—It now remains to be determined whether there is any way by which these losses of rejected heat can be avoided.

There are two forms of engines of class 1st, in which—were it possible to fully avail ourselves of them—all this waste of energy may be avoided.

Type A. The working fluid, if expanded from the temperature and pressure of the boiler or reservoir quite down to the absolute zero, would have all its heat-energy transformed into mechanical work, and there would be no waste. The efficiency would be perfect.

Type B. All heat rejected from the cylinder unutilized may be gathered up and restored to the boiler, there to serve as a basis upon which to pile a new stock of transformable heat-energy, instead of being, as now, rejected from the system entirely and lost. This done, there could be no loss, as all heat leaving the machine would be transmitted to exterior bodies as mechanical energy. Nothing being lost as heat, the efficiency of the engine would be unity and its economy a maximum.

Forms of steam engines may be conceived in which these methods (of saving heat now wasted) may be applied. Practically, however, it is evident, the first form of these two ideal engines can never be made successfully, since it would require to be made of such immense size that all the power derivable from it would be insufficient to move the engine itself. The great expansion of steam necessary to secure the reduction of the mass to the liquid state, even—to say nothing of the probable impossibility of making heat contained in the water available—would compel the adoption of cylinders of such great volume as would prevent the adoption of such engines. All advantage theoretically derivable from their use would be more than neutralized by the immense frictional resistance to which they would be subject, even were it possible to construct them.

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[1] Good engines should not require more than $W = \frac{200}{\sqrt{P}}$, where W = the weight of steam per hour and per horse power; the best practice gives about $W = \frac{150}{\sqrt{P}}$ in large engines with dry steam, high piston speed, and good design, construction and management.

It is also evident, at once, that this objection would be met, but in a less degree, with engines of the second of these two forms, and that the difficulty would be diminished by extending the range of working temperatures and pressures, and also that it would be lessened by any modification which should reduce the proportion of rejected heat. It follows at once that the direction in which we should look for improvement is that in which the well known expedients for increasing the economical value of the common type of engine may be adopted, with the addition of the single expedient here described of saving and returning to the reservoir all rejected heat after its amount shall have been reduced to a minimum by those familiar methods.

XII.—It is not at all impossible that, although the first of these newly proposed types of steam engine is unlikely to have practical value, a modification of that type may, at some future time, come into use and effect a considerable saving of the now wasted heat. It seems improbable, yet it cannot be said to be impossible, that the first method may be carried so far as to secure the greater part of the heat now rejected in the form of latent heat, and that thus only the heat rejected in the liquefied steam will be wasted. Experiment has not yet determined fully, either the law of distribution of heat throughout the scale of temperature, in either water or steam, or the method of change of physical state. It cannot, therefore, be said whether the peculiar and irregular changes of condition of the fluid, which are observed within the range of temperature familiar to us, are illustrations of similar, and possibly more marked, irregularities of physical modification of temperatures nearer the absolute zero or under pressures, which Dr. Andrews, and other physicists, and Perkins, Alban, and others, among engineers, have barely begun to study.

We therefore cannot say what would be the behavior of the fluid in an engine of the first type, and cannot even imagine how far the theory of efficiency of heat engines, as usually accepted, may apply to the steam engine of the now standard type, when the range of temperature of its working fluid shall have been greatly extended. It does seem probable, however, that the steam engine will be found to have a theoretical efficiency, greater than we have previously supposed; and we hope that the practical difficulties to be overcome in the attempt to realize that maximum economy, will be also found to be less than has been anticipated when they are resolutely attacked.

XIII.—It is evident that an engine of class A can only exist when expansion can be carried to such an extent as to leave the working substance at the absolute zero of temperature and entirely deprived of all actual energy.

But Sir Wm. Thomson has enunciated the principle:

"It is impossible, by means of inanimate material agency, to derive mechanical effect from any portion of matter, by cooling it below the temperature of the coldest of the surrounding objects."[1]

Were this principle universally true, it is evident that no engine could be constructed in which the working fluid could be degraded to an average lower temperature than the mean annual temperature of the earth at the latitude of the place in which the engine should be situated. Clerk Maxwell has pointed out the fact that, by a peculiar conceivable, though impracticable, device, the limit fixed by this principle may be exceeded.[11] It is also easy to conceive a much simpler and more natural set of conditions, as will be presently seen, which will permit the limit to be passed, and, possibly, the practical limit to be set back indefinitely in the direction of the zero of heat-motion.

In truth, the principle, as stated, is not correct, except as it implies the existence of certain conditions which are practically persistent, including the use of a permanent gas as the working fluid, or of a substance which does not change its physical state in such a manner, during the conversion of heat into mechanical work, as to invalidate the asserted law.

The fact is, that the conversion of heat-motion into mechanical energy is not limited theoretically, and *may* not be limited practically, by the temperature of the earth's surface.

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[1] On the Dynamical Theory of Heat, etc., by Wm. Thomson: *Trans. R. S. E.*, March and April, 1851.

[11] *The Unseen Universe*, Pages 88–89.

UofM

XIV.—In order to show that heat may be converted into work to any extent, and without regard to the temperature of surrounding bodies, we will trace the process in two cases, viz.:

1. Where the working fluid is a permanent gas.
2. Where a working substance subject to change of physical state is used; for example, steam.

Suppose a working cylinder provided with a tight-fitting piston, the cylinder to be of indefinite length, and the working fluid to be on one side of the piston and a perfect vacuum on the other side. It is evident that expansion may go on indefinitely in such a cylinder, and that the temperature of surrounding objects will have no influence on the extent of such expansion, or upon the completeness with which heat can be converted into work. The working fluid and its work are absolutely independent of everything external to the cylinder in which the transformation of heat into mechanical energy is going on. There is no natural limit to the process of conversion. The piston being free and offering no resistance to motion, we may suppose the expansion to continue until the working fluid, which we will here assume to be a permanent gas, has lost all expansive force, and until all its original heat-motion has been converted into mechanical energy and transmitted to objects external to our prime mover.

The conclusion of the operation leaves the molecules of the gas diffused through a vast space, absolutely at rest,[1] and without vibratory motion. Had not the heat originally contained in the mass been expended in doing work, the magnitude of this space would evidently have been infinite, and the particles, when they had lost all vibratory motion, would have acquired a velocity of translation in lines parallel to the direction of motion of the piston, equal to the velocity due the height through which their original heat-energy would have been sufficient to have lifted them, and equal to the velocity of the particle in its orbit of heat-motion. As, however, this heat-motion has been converted into mechanical energy, the space through which the gas may diffuse itself is restricted.

Now, the removal of a particle from one point in space to another, requires no expenditure of energy. The work done on the particle,

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[1] This may be too unqualified a statement. It is not certain that all heat-energy can be removed from a fluid by expansion. It is possible that an indefinite amount of energy of rotation may be retained after expansion shall have removed all energy of motions of translation of the molecules.

giving it its maximum velocity in transit, is restored by it while it
being again brought to rest. It may thus be possible, in our sup-
sed case, to gather up all these particles and to collect them about
ir common centre of gravity, where they will occupy the volume of
gas in its solid state and at absolute zero. If this had been done
thout collision of particles, no energy will have been expended and
work will have been lost. The mass may now be transferred to
e reservoir, at its original starting point, by the expenditure of an
nount of energy bearing a less proportion to the energy which has
en converted into work as the now indefinitely small volume bears
the volume of the gas when it first issued from that reservoir; the
nount will be insignificant. The operation just traced may thus be
peated indefinitely. The efficiency of our engine is unity, and it is
rfect in every sense.

It needs no further reasoning to prove that the temperature of
rounding bodies has no influence upon the operations here indi-
ed, and that it is a matter of no moment what may be the tem-
ature of the place at which this work has been done. It is further
lent that, if the upper limit of temperature in this example had
n the temperature of the earth's surface at that place, and if the
king substance were air, the reservoir might have been the
osphere, and the operation described would, if continued indefi-
ly, result in the conversion of all heat-energy into mechanical
rgy, and the cooling of the earth down to the absolute zero of
perature. Were it practicable to carry on this operation, and to
ly the mechanical energy resulting from it to the acceleration of
earth's motion in its orbit, its velocity would be increased some-
ng like one mile per second (we assume the mean temperature of
earth at 1500° Cent., and its specific heat at 0·2).

V.—Next, suppose the same operation to be repeated (and in the
e manner), using as a working substance a fluid which loses the
inal physical condition while expanding, and, like steam, con-
es as it expands. In this case, the particles of the fluid, instead
eing indefinitely dispersed, are capable of but a limited expan-
At each instant, a portion of the vapor assumes the liquid state,
endering its latent heat of vaporization to the uncondensed por-
of the gas, to be transformed into work. Thus an accumulation
iquid takes place in the cylinder which becomes very considerable,
in engines operated within very usual ranges of temperature.

Conceive this operation to continue until the limit is reached as before. There will now remain in the steam cylinder a mass of ice at the absolute zero of temperature and a minute quantity of matter at the same temperature, but with its particles widely separated, as in the preceding case. The great mass of the working substance has, in this case, been collected by the process of condensation during expansion, and thus nature has done here what, in the other case, must have been done artificially. It now remains to return to the reservoir the solid mass. This is done, as before, with no great expenditure of energy. The small quantity of dispersed particles may be gathered up and restored, as in the case of the permanent gas, or it may be rejected from the system as of no appreciable value, as may seem best. The process being completed, the system is in condition to permit the commencement of a new cycle. It is evident that the efficiency of this ideal engine is, like that of the ideal engine using a permanent gas, perfect.

XVI.—The practical difficulties which stand in the way of the engineer who endeavors to realize the conditions described, are apparently insuperable. Yet this impossibility of realization is due simply, to the existence of natural conditions which are comparable in their influence, to the action of repellant central forces. We may conquer them in a certain degree by the exertion of any given amount of skill and intelligence; but, as we advance, the difficulty becomes more and more nearly insurmountable by finite power, and the perfect realization of the conditions and of the efficiency first idealized only attainable by the exercise of an apparently infinite intelligence and power. Perhaps a better and more encouraging view would be given by the statement that we may expect to approximate to the realization of the efficiency of the ideal perfect engine more and more closely, as we advance in scientific knowledge and in constructive skill, without limit. It is therefore proper to inquire how far we are limited in this progress by conditions which are now common in the practice of steam engine construction. This we will presently do-

XVII.—Thomson appends to his proposition (which has bee called an axiom) the following note:

"But if this axiom be denied for all temperature, it would have be admitted that a self-acting machine might be set to work and produce mechanical effect by cooling the sea or earth, with no limit but the total loss of heat from the earth and sea, or, in reality, from the whole material world."

Yet we have already seen that such an engine might, by some intelligence, mighty, but not necessarily infinite, be set at work to produce mechanical effect by cooling sea, earth and air. We can see that Omnipotence may thus transform all the heat-energy of the universe into mechanical energy. The "Creation" was either such a transformation of previously existing heat-energy, or an actual production of something from nothing. Either process would accord with all that is taught us by either science or revelation.

Trace, again, the cycle of our ideal engine: a certain weight of working substance is contained within a reservoir, whence it issues, driving a heat engine in which all its available energy is transformed into mechanical work. Restored to the reservoir, it there receives a new stock of heat from the surrounding bodies, which constitute a part of the material world, and another cycle succeeds. This continues until all the heat of surrounding objects, and all they can withdraw from other bodies, is exhausted, and an equivalent amount of kinetic or of potential energy has been produced. *The machine may go on and abstract all the heat from the universe.*

Again, suppose the engine to derive its heat from the combustion of fuel within its reservoir. It is now absolutely independent of all external bodies, so far as temperature is concerned, and knows nothing of so-called limits; its only limits are the temperature attainable by the combustion of its fuel on the one hand, and the temperature at which heat-motion ceases on the other. It may be considered as enclosed within a chamber absolutely impervious to heat and may be placed in a part of the universe devoid of heat, or in a place where it will be surrounded by the heat of a glowing sun; it will, if it does not exhaust its stock of fuel, work on under all such variations of external conditions with unvarying efficiency. This complete separation from external temperatures is one of the most familiar problems of the engineer in his management of the ordinary steam engine, of the air or gas engine, or of any heat engine.

The universe (taking a glance at a wider cycle) is independent of our engine working on heat-energy derived from fuel, so far as regards its stock of heat-energy. The machine receives a certain amount of energy as heat and discharges it as mechanical energy. This mechanical energy is all, directly or indirectly, returned to its original form of heat-energy. The heat received from surrounding space and stored in our coal-beds, is, through the engine, revived, changed in form, then changed back into heat again, and finally thrown back into space.

Thomson's qualification of his "axiom" does not, evidently, confirm the principle which he has enunciated Our self-acting machine *might* cool down "the whole material world."

XVIII.—The practical difficulties which stand in the way of the engineer who attempts to effect the realization of either of the two classes of perfect engine which have been described, can now be easily anticipated, and we may even, to a certain extent, determine how we may best proceed to attack them.

Type A is seen, at a glance, to be an utterly impracticable form of engine. Using a permanent gas as the working fluid, we could not possibly find space for the expansion of the gas to absolute zero. Could we find space, the mean pressure would be so low, and the magnitude of the engine so great, that the resistances due to friction would absorb more than all of the energy developed. But even supposing these two difficulties less absolutely insurmountable, we should still be unable, by any known process, to gather up the scattered particles of the fluid without producing collisions among them, which would generate heat and compel the expenditure of energy in the restoration of the condensed gas to the reservoir. In all known methods of condensation, as in the compression of air for use in mining and other machinery, the heat developed is equal in amount to that given out by the gas in expanding. We are thus practically brought to a limit, in the expansion of the permanent gases in heat engines, at which the *useful* transformation of heat into mechanical energy must cease. This limit is that assigned by Thomson to the ideal engine. If, at some future time, a working fluid and a method of operation shall be found which will enable us to bring the temperature of the expanding substance to atmospheric pressure at less than atmospheric temperature, the limit will be moved farther toward the zero. All known or probable modifications of Type A will be likely to transfer the machine to either Type 2 or Type 3.

The use of other working substances than the permanent gases does not seem likely to overcome entirely the difficulties pointed out as inherent in the use of those gases. It is, nevertheless, perfectly obvious that condensable fluids may prove better working substances the permanent gases, in virtue of the property possessed by them f-aggregation. Such fluids will evidently demand less space into to expand; and the economy of space will rapidly become more ed as the absolute zero is approached. If, at some future time, d shall be discovered which, possessing great volume at high eratures, like steam, shall become wholly liquefied at ordinary eratures, when expanding against a resistance, and on reaching derately low pressure, the efficiency of the engine will become nearly perfect, probably, than in any practicable form of even etically perfect engine worked by a permanent gas. It is evident the property which it possesses of condensing with expansion, doing work, is an exceedingly important and valuable quality e vapor of water, considered as a working substance for heat es.

way has yet been devised, however, of making a steam engine ype A. Assuming it to be possible to make such an engine, steam of 75 pounds pressure by gauge, expansion is supposed on, in this case, until the fluid, by the conversion of all its heat work, has become first liquefied and then solidified. We may estimate the efficiency of such an engine, working without loss iction, or other causes. The work done per pound of steam tted at 75 pounds pressure, and at a temperature of 320° F. Cent.), would be 910,557 foot-pounds; the work expended in emoval of the ice against atmospheric pressure, would be some-; less than 38½ foot-pounds; the efficiency would be (910,557 — ÷ 910,557 = 0·9999 = E. All heat originally existing in fluid having been used in doing work, the rejected solidified er would absorb heat from surrounding bodies, and thus a in portion of energy would be acquired by cooling down those ts. Assuming the engine perfect, structurally, and thus free friction, the upper limit of temperature, as has already been ated, need not exceed that of the surrounding bodies. In the l engine, the duty would be diminished immensely by frictional ther losses.

mplete utilization of all heat is not practicable with the heat e of Type A under any known, or even conceivable, conditions tual construction.[1]

TE.—The two kinds of fluid, working in engines of the Class A, are seen to give aracteristic products of the two known processes of abstraction of heat from

XIX.—It remains to consider the possibility of securing maximum efficiency in actual engines, by the adoption of Type B of Class 1. In this form of engine, all heat rejected from the working cylinder is retained in the system and is restored to the reservoir, thus securing complete utilization of all heat which leaves the machine. Nothing escaping, except in the form of mechanical energy, there can be no waste, and the efficiency of the machi must be unity. The engine is a perfect machine for transforming heat into work.

It has just been seen that a practical and probably insurmountable difficulty arises in the attempt to make an actual engine of Type A, even using a condensible fluid as the working substance, in the necessity of removing not only the ice deposited, but also of gathe ing up the widely-diffused molecules and restoring them to the rese voir, without giving them vibratory motion, and thus expending up them an amount of energy equal to that which they had given during their expansion.

If it were possible to find a working fluid of such character t the desired conditions may be partially realized, and at a compa tively high temperature—that of surrounding bodies—and that condensed portion of the substance may be returned to the reserv the vapor remaining being discharged into the atmosphere, such engine would evidently be a simple modification of the well-kn high-pressure expanding non-condensing steam engine. In t latter the steam is largely condensed by expansion as a worki fluid, and the water is often, and may be always, returned to t boiler. The uncondensed portion is discharged into the atmosphe To convert this engine into a machine of Class B, it will be necess to find a way of restoring *all* rejected heat to the boiler.

Type B, in which all unutilized heat is restored to the reservo comprehends engines of two very different kinds. These are:

1. Heat engines in which the rejected heat is transferred from t mass of working substance discharged from the working cylinder the end of the stroke of the piston, to a mass of metal or other he

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fluids: 1. Forcibly compress the fluid, removing the heat of compression as rap as it is generated; the product is, after all heat has been removed, a mass of m mum density, probably solid in all cases, and at the absolute zero of temperat 2. Abstract the heat contained originally in the mass, by causing its expan against a resistance: the product is a diffused mass, without tension, of mini possible density, and at the absolute zero of temperature.

·bing material, and from the latter again transferred to another
a new charge of working fluid which is about entering the
·voir to take up a new stock of heat energy.

Heat engines in which, as in the ideal engines already de-
›ed, the rejected working fluid itself, with its contained unutilized
, is all returned to the reservoir.

X.—Engines of the first of the two kinds into which Type B is
divided, and in which the working fluid is usually air, have fre-
ıtly been designed. The mechanism by which the heat is stored
restored by transfer has been called the "Regenerator." Engines
ng regenerators have always been supplied with air as a working
. The regenerator consists of a mass of metal, usually made up
collection of conveniently disposed sheets or wires, into which or
ugh which the rejected gas is discharged, and through which or
ı which the entering charge of the working fluid passes on its way
he cylinder. The mass is heated by the transfer to it of heat
ı the rejected charge, and this heat is returned to the entering
·ge to be more or less thoroughly utilized by expansion at the
ceding stroke.

he regenerator never operates with more than approximate thor-
ıness. The time allowed for the transfer of heat from the regen-
or is not just equal to that given for absorption by it. The
plete transfer of all heat, and with equal rapidity in both direc-
s, demands an equal mean difference of temperature between the
ıl and the gas, urging the flow of heat in the two directions.
· is not secured, and the regenerator either continually warms
y the accumulation of heat, or it acts very inefficiently. In
ıir engine of Stirling, in which this device was first used, about
', the amount of lost heat was still very considerable. The en-
g charge of air is itself heated before passing through the regen-
·r, and is thus prevented from taking up additional heat readily
promptly. The rejected charge is sent through the regenerator
very great rapidity and is rapidly expanding as it passes. It is
given time enough to discharge its heat into the metal received.
it necessarily retains a considerable proportion as latent heat of
ısion. Nevertheless, air engines fitted with regenerators have
·times proved to be very efficient. The engines designed by
sson for the steamer of that name were found by Prof. Norton to
developed their full power (300 H. P.) with a consumption of but

1·87 pounds of coal per hour and per horse-power. The transfer of heat from the fuel to the working fluid was here found to be, as is always the case with this class of engines, very ineffectively secured. The gases are too nearly perfect non-conductors to permit rapid absorption or discharge of heat; and this fact is one principal cause of their inefficiency; it so greatly reduces the efficiency of their furnaces that the net efficiency of the machine becomes very much less than it would be were the furnace as effective as are steam boiler furnaces. It is evident from what has been stated that the regenerator, as applied to engines having permanent gases as their working fluids, does not yield a satisfactory economy by storing and restoring rejected heat.

The regenerator is entirely inapplicable to engines in which steam and other saturated vapors are employed. The rejected heat, in these engines, is principally conveyed from the working cylinder in the form of latent heat of vaporization, and can only be removed from the exhausted charge by the condensation of the steam. But this condensation involves the degradation of the rejected heat to a temperature at which it is no longer transferable to the entering charge of the working substance. The use of a regenerator is therefore out of the question in engines in which vapors of liquids similar to saturated steam are employed.

It is, however, possible to secure a partial saving of heat rejected from one such engine, as the steam engine, by using, as an absorbent of that heat, a liquid having a boiling point at a temperature considerably below that of the liquid formed by the condensation of the first used vapor. The transfer of the heat rejected from the first engine to the liquid contained in a reservoir forming a part of the second engine, results in the condensation of the steam in which it was originally contained and the simultaneous vaporization of the second liquid. The latter is then used in the production of power by the utilization of a part of the heat thus preserved. Could a series of substances be found thus related to each other, this process could be continued indefinitely, or until the available energy ceases to be competent to overcome frictional and other resistances. The engine which formed the terminal of the series would waste all heat rejected from its cylinder. Such a combination as is here described has been made, two engines being used, and has been known as the "Binary engine." The first of the pair has been worked by steam, and the second by the vapor of ether, of chloroform, or of the bisulphide of carbon. The efficiency of the combination has considerably exceeded that of the steam engine; but it has not been sufficient to compensate the practical difficulties met with in the construction, and especially in the operation, of such engines.

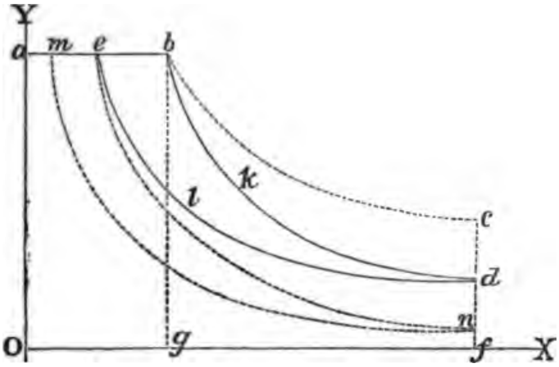
XXI.—Were it possible to conduct this operation of re-working the rejected heat by passing it through the first cylinder again, instead of being compelled to use additional engines, it would be decidedly more satisfactory than the use of the Binary class of engines. We may naturally next consider the possibility of returning to the reservoir all heat rejected in engines using vapors, as of water, as their working fluids. As the regenerator system is inapplicable here, it is necessary to secure the return of that unutilized heat by restoring to the reservoir all exhausted gas or liquid, or both, without seeking to remove from them and to restore separately the heat with which they are charged. Fortunately, the conditions which make the use of the regenerator system impracticable, are favorable to the adoption of the expedient which has been described as characterizing the operation of engines of Type B.

As has been seen, the expansion of steam doing work results in the condensation of a portion of the vapor. The weight of steam condensed bears a proportion to the weight of steam supplied, which is greater as the work done by expanding that steam becomes a greater proportion of the mechanical equivalent of the thermal contents of the steam when supplied to the working cylinder.

Suppose the expansion to be carried so far that one-half of the vapor becomes liquid. Imagine the water of condensation separated from the uncondensed vapor, and the two masses returned to the boiler separately by compressing pumps. The return of the water would involve the expenditure of an amount of work measured by the product of the volume of that water into the difference of pressures in the boiler and in the receiver into which the exhaust has been discharged. The return of the uncondensed steam would involve not only the return of the charge of heat contained in that steam, but also the return of all the energy which the vapor had yielded during its expansion; since an equivalent amount of heat would be generated by its recompression to boiler pressure.

Under the conditions now assumed, it is evident that only that portion of the heat entering the engine which is surrendered by the condensation of steam doing work can be utilized. It is als that, in this form of engine, no heat can be lost; and, cons that the engine of Type B, which is operated as just indic have yielded the exact equivalent of the net amount of heat upon it. All heat rejected from the working cylinder, u being returned to the boiler, there to form "a basis on whi up a new stock of utilizable energy," the engine is a engine" in a broader sense than that adopted by Carn further evident, that perfect efficiency is given for all range perature, and that what working fluid shall be adopted temperatures shall be chosen, will be determined simply by conditions to be ascertained by experiment.

The work done in restoring the water of condensation to being so small in amount that it may be neglected, the ratio o work done in restoring rejected heat to the work done by t on the p be the ra weight of stored to er of th to that su the worki der at eac Altering of the com having an of 0·25, i gine of Type B, the quantities of work done during expa during compression will have the ratio, nearly, of 1 : (1 = 0·75.



The indicator diagram of our new engine will be simila shown in the accompanying figure, in which the ordinat curve measure the pressures, and the abscissæ are propo the volumes of the expanding fluid. The steam expands volume $g\ O$ to the volume $f\ O$, when doing work, and pressure $O\ a$ or $b\ g$ to the pressure $c\ f$, when expandin ing to Boyle's law. Doing work, however, the gradual con of the fluid reduces the pressure during expansion, an becomes $b\ k\ d$, instead of $b\ c$. When the attempt is restore the rejected fluid to the boiler, the compression would naturally cause the line *d k b* to be retraced; but having removed the water of condensation from the engine separately, it cannot add, by its re-evaporation, to the tension of the steam under compression, and the latter must behave more nearly like a perfect gas, causing the line to take the direction *d l e*. The net result is the production of mechanical energy represented by the area *e b k d l e*, and the expenditure of an equivalent amount of heat energy, plus the amount of energy required to return the water of condensation to the boiler. Had, in this case, the steam been cut off at an earlier point in the stroke, as at *e*, the area *e n m* would have represented the quantity of heat transformed into work. It is evident, that the more the steam is expanded, the greater will be the proportion of steam condensed, and the less the amount remaining to be compressed to boiler pressure, and the less the weight of steam required to be supplied to the engine per unit of work done. It follows that, to secure an engine combining high efficiency with small volume, it will be advisable to employ steam of high pressure, and to expand it as much as may be found practicable. The new type of engine can, probably, only supersede the common form when engineers can employ steam of very high pressure, and adopt much greater range of expansion than is now usual. Great velocity of piston and high speed of rotation are also essential in the attempt to make this revolution in steam engine construction a success.

XXII.—The term efficiency requires more accurate definition than is usually given it in works treating of heat engines. There are several distinct quantities to which the term is often applied. The *efficiency of the fluid*, by which should be understood the ratio of the quantity of work done by the working substance to the mechanical equivalent of its thermal contents at the instant of entering the cylinder of the engine, and which, measured by the quantity $\frac{Q - Q'}{Q} = E$, is often confounded with the *efficiency of the engine*, which latter is the ratio of work of the engine during a given interval of time to the mechanical equivalent of the heat supplied to the engine in that time. The *efficiency of the boiler* is the ratio of heat delivered from the boiler in dry steam to the amount of heat developed in its furnace by the combustion of fuel. The *efficiency of* *the furnace* is the ratio of the amount of heat rendered utilizable by transfer to a boiler, by that furnace, to the amount of heat generated by the perfect combustion of the fuel supplied. The *efficiency of the engine* is also often taken as the efficiency of the whole combination of engine, with its fluid and with boiler and furnace working together. This latter is also often confounded with the efficiency of the fluid as well as with the efficiency of the engine proper. It is generally assumed that the theoretical efficiency of the steam engine, including its boiler, is limited by the efficiency of the fluid, and that, for example, the efficiency of an engine working between the limits of 800° and 600° on the absolute scale can have no greater efficiency than that measuring the efficiency of the fluid =, say, 0·25. That this is not the fact is seen when it is remembered that our ordinary calculation of the efficiency of the fluid takes no note of the temperature of the fluid supplied to the reservoir or of the method of disposal of rejected heat, which, as we have seen, is usually partly saved, and may be wholly restored.

Assume the limits of temperature and pressure of two engines to be the same, the upper limit being 90 pounds absolute pressure and the temperature 320° F., or 180° C., and the lower limit 2 pounds and 126·27° F., or 52·37° C., the working fluid to be steam, and one engine to be of the ordinary type, the other of the new type. Let both engines expand completely from the upper to the lower limit. First determine the value of $\frac{Q-Q'}{Q}=E$ for the common engine, taking Q as the net amount of heat supplied to each pound of steam by the fuel in the boiler, and Q' as the quantity rejected from the cylinder and discharged from the engine, assuming no losses to occur by conduction, radiation, or friction.

E is evidently the efficiency of engine and boiler working together, and its estimation should afford a basis for the calculation of th weight of steam required by the engine, and of water to be fed to th boiler. The efficiency of the furnace and calorific value of the fu being known, the weight of fuel may then be calculated.

Taking the feed water into the boiler at a temperature of 110 F., which is a very usual temperature of feed, the total heat steam supplied to the engine at a pressure of 90 pounds per squa inch above a vacuum will be 1211·5 — 110 = 1101·5. The therm contents of each pound of steam rejected from the cylinder at

sure, the temperature being 126·27, will be, if reckoned
riginal temperature of feed, 1152·5 — 110 = 1042·5.
ısted with each pound of water so rejected, will be 126·27
6·27 thermal units.
ıl weights of steam and of the water rejected, per pound
pplied to the engine, may be readily calculated. It has
by Rankine that steam, expanding under the assumed
ınd condensing, as it does, in a non-conducting vessel,
relation of volumes and pressures which may be approx-
ıressed by an equation of the form $P V^x = C$, in which
t of the quantity V has a value exceeding unity. Ran-
this value to be about 1·1111+; but it has been since
by Zeuner to be more nearly 1·333+, which latter value
n as correct. It is confirmed by Cazin and Hirn.[1] The
ne pound of steam at the temperature and pressure at
ers our steam cylinder, is 4·72 cubic feet. The value of
ıre, $P V^{\frac{4}{3}} = C = 90 \times 144 \times \overline{4\cdot72}^{\frac{4}{3}} = 102\cdot611$. The
eam exhausted from the cylinder—expansion being taken
ı carried so far that the pressure at the opening of the
ve is 2 pounds per square inch—must be $V = \overline{C \div P}^{\frac{3}{4}} =$
$2 \times 144)^{\frac{3}{4}} = 76\cdot53$. But the volume of 1 pound of steam
ısure is 172·4 cubic feet. The quantity of uncondensed
ted from the cylinder, per pound of steam supplied, is,
6·534 ÷ 172·4 = 0·444 pound. The weight of water
(172·4 — 76·5) ÷ 172·4 = 0·556 pound. The steam
ı it 1042·5 × 0·444 = 462·85 thermal units, and the
16·27 × 0·556 = 9·05 units. The sum 471·90 units, is
ıount of heat wasted by rejection from the engine. The
has been utilized is 1101·5 — 471·90 = 630·6. The
, is (1101·5 — 471·9) ÷ 1101·5 = 0·57, or nearly six-

ıen seen, had the working fluid been a permanent gas, the
ıuld have been one-fourth. The difference illustrates the

This value of x may have been here accepted on insufficient authority.
nner, in his treatise (French ed., p. 332), makes it 1·135, and Grashof
Zenner also shows that the value of x is reduced by the addition of
eam. Laboulaye still insists, also, on the value 370 kilogrammetres,
for Joule's equivalent, which, if correct, would modify the theory

superiority of the condensable vapor as a medium for conversion of heat into work. Assuming perfect efficiency, aside from the defect just estimated, this engine should require but $(1{,}980{,}000 \div 1101{\cdot}5 \times 772) \div 0{\cdot}57 = 4{\cdot}09$ pounds of steam, or about two-fifths of a pound of coal per hour and per horse-power. An actual engine, working steam in this manner, usually consumes at least five times this amount. The difference between the estimated theoretical and the actual efficiency, has usually been supposed to be much less, and it has been stated by the writer, as well as by other engineers, that the range left for improvement, by modification of the structure of the common engine, is much less than it is here shown to be.

The direction in which further improvement must take place in the standard type of engine, is plainly that which shall most efficiently check losses by internal condensation and re-evaporation by the transfer of heat to and from the metal of the steam cylinder. The condensation of steam doing work is evidently not a disadvantage, but, on the contrary, a decided advantage.

To secure this vitally important economy, it is advisable to seek some practicable method of lining the cylinder with a non-conducting material.[1] The loss will also be reduced by increasing the speed of rotation and velocity of piston. Where no effectual means can be found of preventing contact of the steam with a good absorbent and conductor of heat, it will be found best to sacrifice some of the efficiency due to the change of state of the vapor, by superheating it and sending it into the cylinder at a temperature considerably exceeding that of saturation. With low steam and slowly moving pistons, it is better to pursue the latter course than to attempt to increase the efficiency of the engine by greater expansion.

Increasing steam pressure and expanding to a greater extent will give theoretically slightly increased economy. Repeating the calculation made above, using as constants the temperature, volumes and pressures of steam entering the cylinder at 250 pounds, and expanding down to the same point, it will be found that the gain in efficiency is but a few per cent. It is not in that direction, therefore,

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[1] This plan was adopted by Smeaton, in constructing Newcomen engines a century ago. Smeaton used wood on his pistons. Watt tried wood as a material for steam cylinder linings. That material is too perishable at temperatures now common, and no metal has yet been substituted, or even discovered, which answers the same purpose.

: to look for important improvement in the use of the
pe of engine. There seems no alternative but to attempt
into an engine of our new Type B, and look for the dis-
ı efficient non-conducting lining material which shall enable
ıe, probably, thirty per cent. of heat supplied which is trans-
e condenser by internal condensation and re-evaporation.

-The question whether such an engine as that which has
described as type B can be made practically successful,
e answered after careful and intelligent experimental in-
The advantages promised by the results of theoretical
n, will be greatly modified by conditions unavoidably intro-
ıe construction and operation of the machine. Some of
tions may be anticipated, and their effect upon the efficiency
ıe success of the engine in other respects may be indicated
. It is even possible that a rough approximation may be
imating its real practical value.
ntial requisites of a successful type of engine are: safety;
durability; simplicity; compactness, and a moderate first

ıay always be secured by intelligent design, good material
ıanship, and skilful management. The new type is
ılly liable to objection on the score of danger, except
it may prove essential to its success to work at ex-
high pressures; but as pressures of 1000 and 2000
re controlled without accident, forty years ago, by Per-
by Albans, it is not to be anticipated that danger
arily be incurred at pressures far exceeding those in
to-day, yet far within the limit already attained. The
of the engine will also be determined by the same condi-
safety, and is to be assured in the same manner. The
omy to be secured by its adoption is largely determined by
ich it may be found necessary to give it; for its losses will
wholly due to friction. In simplicity, it is not likely to
ith the common engine, since it must be fitted with some
for compressing the steam to be returned to the boiler. It
obable, however, that the new type may be yet given a form
may compete nearly as successfully, in this respect, with
ry engine as has the compound type of the latter with the
s.

To determine the probable size of the engine of Type B, it need only be remembered that, as it must expend, in returning to the boiler its unutilized heat, a proportion, $1 - E$, of the power produced at each stroke, it must, when running at the same speed, work off a greater volume of steam in doing the same work, in the proportion $1 \div E : 1$. But the larger engine will be subjected to frictional resistances which will be similarly increased, and this, in turn, will exaggerate the size of engine and the losses of efficiency. Replacing an engine of the old form, having an efficiency of 20 per cent., by an engine of the new type, it will be necessary to either make the latter of five times the piston displacement of the former, per stroke, or to run the new engine at five times the speed of piston of the old. It should be the endeavor to make the change in the last named of the two ways, not only as a matter of economy of first cost, but as a means of reducing losses of pressure by internal condensation and re-evaporation. It is evident that such losses of pressure do not affect the estimated economy of the engine, since, however much heat is thus caused to be rejected from the cylinder, it is all saved and restored. The higher the steam pressure used, and the higher the efficiency due to increase in the amount of heat converted into work, the more favorable do the actual conditions of use become to the new engine.

Assuming an engine of the proposed type to have an estimated efficiency of fluid of 50 per cent., it must be made, at the same piston speed, twice the size of the engine of the common form. To allow for increased frictional and other losses, an addition in enlargement of probably 25 per cent. must be calculated upon. The theoretical cost of the horse-power will be about 5 pounds of steam per hour. The losses of heat by conduction and radiation, which, in the common engine, may be taken as 10 per cent. as a maximum, will become 20 per cent., and will bring up the consumption of steam to 6 pounds per horse-power developed in the cylinder. The resistance due to friction, which may also be taken at 10 per cent., will be doubled also, and this will raise the expenditure of steam to above 7 pounds. We may take as the probable consumption of heat in such an engine, per hour and per horse power, very nearly 8000 British thermal units. With good boilers, this will call for the combustion of about three-quarters, or four-fifths, of a pound of good fuel—about one-third the amount demanded by the very best engines ever built for transatlantic steamers, and one-quarter as much as is usually consumed with very

marine engines of the now popular compound type. But the
age to be secured by the adoption of this type becomes greater
igher pressures, and will therefore be likely to appear greater
·eater continually. With what would now be thought exceed-
high steam, and with vastly increased piston speeds, such as
most certainly be adopted in the future, the new type will ap-
very much more promising plan than it now does.

now standard engine drives a steamship across the Atlantic
ı consumption of 1000 tons of coal; the new engine should do
ne work on 250 tons. It should occupy but little more avail-
)ace in the ship, but would weigh twice as much unless the piston
were correspondingly increased. The greater weight of engine
be vastly more than counterbalanced, however, by the reduction
ce and weight devoted to boilers and coal-bunkers, to one-third
-fourth their present capacity. If this type of engine should
to be available with steam pressures that are soon to be found
 controllable, it is certain that it will be even more advanta-
for marine purposes than for use on land, where these reductions
ce and weight are of less importance. Even its application to
)tives would not be thought impossible.

IV.—Several engines of this type have been planned by the
, in all of which the rejected heat is returned to the boiler.[1]
 expert mechanical engineer will readily devise many methods
ıich the standard forms of steam engine may be modified and
'ted either into illustrations of this Type B, or into engines of
2, in which the rejected heat is very nearly all restored to the
When this possible "engine of the future" is likely to be
uced, if at all, can be scarcely even conjectured. It seems evi-
hat its success is to be secured, if its introduction is attempted,
 adoption of high steam pressures, of great piston speeds, by
ınd skill in design, by the use of exceptionally excellent mate-
)f construction, and by great perfection of workmanship and
gence in its management. There seems no tangible obstacle to
roduction; but engineers who have seen the slow progress of the

---

idea first suggested itself to the mind of the writer in 1858-9, when at Brown
ity, and while designing a peculiar form of "drop cut-off engine," which was
d to work with exceptional economy. The plans then conceived have gradu-
umed a different shape, but still embody the essential principles here outlined.

compound engine and of surface condensation in marine construction will anticipate no very rapid progress here.

Experiment and experience will probably lead gradually to the general and safe employment of greatly increased steam pressures and very greatly increased piston speeds, and will ultimately reveal and remove all those difficulties which must invariably be expected to be met here, as in all other attempts to effect radical changes, however important they may be. We are continually learning that the use of steam as a medium for transformation of heat into mechanical energy is more advantageous than it had been supposed. The corrected estimates of the efficiency of the steam engine given above, show it to be capable of far more perfect utilization than generally accepted authorities had supposed possible. It is not improbable that even these estimates give a very inadequate idea of the true efficiency of the perfect steam engine. We know almost nothing of the physical properties of steam which are mostly concerned in its utilization in heat engines at the high pressures which we know are attainable; and it is impossible to say that the modifications of specific heat and of pressures at such high temperatures may not be such that it may prove a vastly more efficient working substance for the heat engine, at such temperatures and pressures, than we are led to consider it from our knowledge of its properties at the now usual working pressures.

STEVENS INSTITUTE OF TECHNOLOGY,
Hoboken, N. J., *April*, 1877.

ADDENDUM.—The probability of the successful adoption of the type of heat engine described in the above paper, is evidently largely dependent: first, upon the correctness of Rankine's or of Zenner's determination of the value of the exponent in Poisson's formula, $P V^x = C$; secondly, upon the possibility of obtaining a high value of that exponent in actual work. It is evident, that if Rankine's value, $\frac{10}{9}$, were correct, it would be quite out of the question to expect that an engine can ever be built in which the magnitude of the machine should be so far reduced, in proportion to power developed, as to insure the success of this plan. If the larger value, $\frac{4}{3}$, is correct, it is equally evident that success is possible, even if not extremely probable, assuming that the process of internal condensation and re-evaporation may be checked.

The writer has received, since the above was written, a statement of the results of experiments upon a quick-running portable engine made by Mr. J. C. Hoadley, to determine the value of the exponent, x. In that instance Mr. H. finds the value of x to be 1·247, or nearly $\frac{5}{4}$, in an engine which was not constructed with any special provision for checking this kind of loss, except so far as it is reduced by high speed of piston and frequent reciprocation.

This may, probably, be taken as another proof of the erroneousness of Rankine's value, and the more probable accuracy of Zenner's, and as indicating the possibility of, at some future time, securing a nearly perfect working of the steam in the cylinder, thus attaining, approximately, the perfect efficiency of the new type of engine.

R. H. T.

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Stevens Institute of Technology, Hoboken, N. J.

THE
MECHANICAL ENGINEER:
HIS PREPARATION AND HIS WORK.

An Address

the Graduating Class of the Stevens Institute of Technology.

BY

R. H. THURSTON, A.M., C.E.,

PROFESSOR OF MECHANICAL ENGINEERING.

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PER ASPERA AD ASTRA
EDWIN A. STEVENS

[illegible]

ADDRESS.

LADIES AND GENTLEMEN:

GENTLEMEN OF THE GRADUATING CLASS: It is with sincere pleasure, mingled with equally sincere regret, that I have consented to address you on this last day of your appearance here as undergraduates, and to congratulate you on the occasion of your graduation.

These four years just past have been years of pleasant intercourse, of useful training, and of profitable study.

You have had opportunities such as were entirely beyond the reach of all, but a few years ago, and such as but very few can obtain to-day. You have taken full advantage of your good-fortune; you have utilized these opportunities in the best possible manner, and are now prepared to take leave of your instructors and your college mates, and to go out into active business life.

An occasion like this is always one of great interest, not only to you who are about going forth into the world, but to us, your friends, who have already had some experience of its toil and its pleasures, its responsibilities and its rewards, and who can, therefore, share in your excitement and sympathize in all those emotions which are awakened in the breasts of young men ambitious and determined, well trained and educated, as they approach this great turning-point, and realize what duties and what opportunities lie before them.

The methods of education which have been adopted in your preliminary training are in some respects peculiar, and the facilities for attaining that object have been exceptional. That object itself is not precisely that sought in other colleges. While seeking to secure to the student that retentive memory, that power of observation, and that habit of concentration which are essential to mental and intellectual development, and while never forgetting the great object of all education—the attainment of correct habits of thought, of the power of logical deduction, of a sound judgment, and of a knowledge, full and accurate, of history and philosophy, of languages, and of the mathematical and physical sciences, the cultivation of the mind and the acquisition of knowledge for its own sake—with all this it has been the design of the Trustees of the STEVENS INSTITUTE OF TECHNOLOGY to unite, in carrying out the noble work entrusted to them, a special training in a field which is opening widely before you, and which demands from those who labor in it an extent of preparation and a range of acquirements which, I am confident, neither they nor any of us can fully realize.

This great field is that in which are met all of the useful arts of construction—all of those arts which assist in making up the material of civilization.

We are just beginning to learn that the sciences and the arts are not absolutely independent, that they are not in nature antagonistic but that each may, and that each must, aid the other in the acquirements of victories either of peace or war. Recognizing this fact, and believing that, while training young men to become all that is expected of the scholar, it was quite possible to assist them at the same time in acquiring the rudiments of the science of that profession which has been honored by the great men whose names are familiar tō you who have profited by their success, this attempt has been made to unite these requisites, and to give you an opportunity both to become familiar with science and to learn something of art.

It has been attempted to fit you to enter a splendid profession, acquainted with all of those branches which are the essential materials of a foundation upon which it remains for you to erect a superstructure which shall be an edifice as noble in magnitude as exact in proportions, as graceful in form, as beautiful in its adornments, and as great in its value to yourself and to the world, as your own talent, industry, integrity, and ambition shall make it.

You graduate not only with a parchment certificate of your ability to enter one of the most important, most lucrative, and most honorable of the professions, but with much else that is essential to all who aspire to become wise men and useful citizens.

You have been enabled to acquire an unusually extended knowledge of MATHEMATICS—that oldest of the sciences, which had its origin in prehistoric times among the earliest Asiatic civilizations—that science which had its first known expounder in the old Hindoo, Arya Bhatta.

You came to us from the schools with just that knowledge of mathematics which placed you beside the ancient Greeks and the Arabians of two thousand years ago. Euclid was your preceptor in geometry, and Diophantus was your antecedent in algebra. Under the instruction of your genial teacher, you have become familiar with the fame and with the splendid work of those great men: Cardan and Partalea; Descartes; Lagrange and Euler; Gauss; Horner; Sturm and Leibnitz; Bernouilli; Newton; and Laplace. You have discussed Galileo's theories, Hooker's ingenious problems, and Navier's classic discussions and elegant hypotheses. The names of Adams and Leverrier, De Morgan and Peirce, suggest to you possibilities which awaken your noblest aspirations.

You have been taught here, not only a course of pure mathematics, such as was formerly prized principally for the mental training which it gave, but you have been led to make useful applications to those problems of practical, every-day life and work which, while no less valuable as intellectual gymnastics, give development to good common-sense, and which assist to make the man as symmetrical as the gymnast and as skilful as the world's best workers. You have not only been given a set of useful tools, but you have been shown how to handle them.

But the greatest value of these acquirements, as aiding you professionally, will be seen later in life, when, after years perhaps of hard work and of severe competition, you may have arrived at the height of professional practice, and when you will begin to meet with those exceptional problems difficult of solution by all, and soluble by very few.

It is then that you will see most plainly the advantages of this early and extended preparation, and will learn that success in these exceptional cases may make you leading men in your profession. You will find multitudes doing ordinary work well; but, between the leaders, success in competition is won by overcoming great and rare obstacles.

Great fields of application lie before you in the new, and as yet undeveloped, science of Thermodynamics, and in its application to the theory of heat-engines and to practical problems of inestimable importance. Those of your comrades who have preceded you have shown you where to look for them.

With you, the investigation of the minor, yet inconceivably fruitful, principles of this science will be an interesting field of research. With these, and with the various problems in civil construction and in naval architecture, and the art and material of war, as well as in all branches of engineering which lie open to you, there is ample opportunity to apply all the knowledge that you may ever acquire of this Science of the Exact Sciences. Do not, therefore, stop at the threshold of this temple, but go forward and explore it as far and as thoroughly as opportunity and ability will permit.

In the laboratory you have pursued the study of CHEMISTRY. This, dry and unattractive as it is to some minds, is nevertheless one of the most beautiful and most wonderful, as well as most important, of the physical sciences. It is one which presents, in countless beautiful experiments, phenomena of the most intensely interesting character.

You have become practically acquainted by daily contact with this venerable science, born of mystery and nursed by those strange old alchemists, Albertus Magnus, Geber, and that wonderful man Roger Bacon. By your own work in the laboratory you have learned to appreciate the magnificent achievements of Scheele and Lavoisier, of Boyle and Priestley, and of all their numerous successors. You will have frequent occasion to apply your knowledge of this science, and to put in practice that adroitness in manipulation which you have here acquired while following in this path your skilful instructor, and while studying the latest work of Wöhler and Deville, of Frankland and Calvert, of Bunsen, Liebig, and Wurtz, and of Draper and Gibbs.

Metallurgy offers you a score of attractive fields for its application and for study and most valuable research, and in every art its value is becoming fully recognized. This field has been fairly opened by the technical chemist and by those who have distinguished themelves in pure research. New materials, new processes, and new ndustries are continually being created by the students of this beauiful science. You will be sometimes called upon to examine them n the course of professional practice. When this occurs, study the ubject cautiously, critically, and thoroughly, deceiving neither yourelf nor your client.

That later science, PHYSICS, or Natural Philosophy—I like the old name best—has been opened to you with all the completeness that hese collections of delicate and wonder-working apparatus and the knowledge and skill of your accomplished preceptors could secure.

The beautiful phenomena of OPTICS have become familiar to you by frequent observation; and their occasional exhibition in this hall on a grander scale has assisted to impress upon you their characterstics. Beginning with the simplest principles known to the Arabian philosopher, Alhazen, and to the Egyptian, Ptolemy, you have advanced those stages of progress which were marked by the works of Bacon, Brewster, and Young, the discoveries of Kepler and Biot, of Huyghens and Frauenhofer, learning the principles analytically expressed by Newton and Descartes. You have reviewed those ater discoveries of the astonishing applications of the beautiful properties of the spectrum, and have seen them illustrated in the researches of Kirchhoff and Bunsen, and of Huggins and Miller, and of our own Professor Young. You have yourselves read, in a ray of light, the composition of a complex metallic alloy, and of the salts of every kind collected in the laboratory of our President, and you have, in the same curious way, seen the constitution determined of the sun and the farthest stars.

When Gilbert wrote his " De Magnete," two and three-quarters centuries ago, he was a more learned electrician and knew more of magnetism—I am sure, for I remember catechising you—than were some of you who are about to leave us, when you came to us four years ago. You now have repeated the rude experiments of Otto Guericke and of Dufay; and the simple demonstration, made by Franklin a century and a quarter ago, of the identity of the electricity of the lecture-room with the " fire of heaven," is a familiar legend. The theories of Dufay, of Coulomb, and of Ampère, the labors of Humboldt, and the discoveries of Oersted, Volta's invention, the apparatus of Wheatstone, and that splendid triumph of mind over matter which has also made the name of Morse famous—these are all, in your minds, suggestions fruitful of reminiscences of the achievements of the past, and reminders of worlds yet remaining to be conquered. In this department of knowledge Faraday followed Sir Humphry Davy, and Tyndall is still at work earning fresh laurels. You have been fairly inducted here. Why need you stop at the entrance to this beautiful and attractive path? Those of you who propose to practise in that division of the province of mechanical engineering will find the fullest opportunity to exercise your acquirements as physicists in the application of Thermotics. The sciences of heat and of the chemico-physical phenomena of evaporation and combustion and of thermodynamics will find daily application in your work, which affords a field, not only for the use of that theoretical knowledge obtained from the text-books, but for the exercise of all that familiarity with the laws and the facts of the sciences which is secured by actual manipulation and personal attention. They will demand such methods as you have practised in the Physical Laboratory, where you were not simply told how the thing was done, but were shown how to do it for yourself. The design and construction of heat engines, the study of special applications of thermotic principles, and, sometimes, their theoretical investigation, are now the occasional tasks of the engineer, and may, after a time, become yours. They are every day arising more frequently and assuming higher importance. The work of Clausius and Thompson and Rankine is simply preparatory to an immense variety of useful applications, which you may sooner or later be called upon to make.

The study of MODERN LANGUAGES has pleasantly varied your course. No engineer, whether young or old, whether just entering the profession or in the midst of most engrossing practice, can fail to find a knowledge of the principal European languages of great value professionally, and extremely desirable as an accomplishment. To you the great literatures of France and of Germany, with their stores of fact and of fable, of history and of belles-lettres, have been revealed. You have been prepared to make your own all of those splendid treasures of scientific learning which have so long enriched the French, and all of the inestimably valuable literature of engineering of which German literature is now so prolific. The wild epic which recounts the fate of Siegfried and Kriemhild and of all the Nibelungen chiefs; the dignified poems of Goethe; the lovely verses of Schiller, whose "Song of the Bell" indicates his familiarity with our craft; those grand philosophies which rise above all atheistic speculations—these are all accessible to you. The purely scientific and technical works of Weisbach, Reauleaux, and Grashof are placed before you. Side by side with all these are the sweet songs of the Troubadours and the Trouveres, the philosophy of Pascal, the rich dramas of Racine, the pleasing romances of Madame de Staël and of Châteaubriand, the strange stories of Victor Hugo and of Jules Verne, and all the less attractive, perhaps, but more practically useful professional memoirs of Navier and Morin, of Claudel and Poncelet and Tresca. In both languages, as in the English, you will find the periodical literature most immediately useful, as presenting you with the latest discoveries, the subjects of most direct importance, and the views of contemporary authorities.

Your studies of HISTORY and of ENGLISH LITERATURE AND LANGUAGE have been by no means the least important part of this preparatory training. This branch of your education is not only necessary, as of frequent use, but it is a most satisfactory and thoroughly enjoyable portion of your knowledge. While studying the history of civilization, and making a retrospect of the growth of nations and of the development of races, you have traced the rise and progress of religious beliefs, and have seen the evidence of their essential influence—even of the crudest of the earlier systems—in assisting the advancement of mankind, intellectually and even physically, as well as morally, and in promoting that higher humanity which stands next to divinity and religion. You have watched with Gibbon and Macaulay and Hallam the rise and fall of older empires, and with Bancroft and Prescott and Carlyle and Buckle and Motley have seen the ebb and flow, with political changes, of all human knowledge and intelligence. From Whewell you have learned how the inductive sciences had their origin, by whom they were nurtured, and by whom most nearly perfected. You have followed their development from the earliest times, and have seen how the Hindoos, the Chinese, the Assyrians and Phœnicians, the Egyptians and the Greeks, the Romans and their modern successors among European nations, one after another, in turn, took up the standard, and, bearing it bravely a few centuries, gradually lost strength and vitality as they passed the epoch of maturity, and finally dropped it into younger and stronger hands, while they relapsed into sometimes even darker barbarism than that from which they first emerged. Now you are coming up to assist a later and more favored people—the *Eclectic Nation*—in sustaining and advancing it in its turn, and in the still nobler work of casting our light back upon those who have fallen behind us, revealing to now less privileged nations the glorious fruits of their earlier efforts. Your knowledge of English literature will prove through life a never-failing well-spring of pleasure. Gower and Chaucer will entertain you with their quaint old English. Shakspere's kaleidoscopic plays, consummate in art, ennobling in sentiment, rich in incident, instructive in matter and fascinating in manner, wonderful in delineation of character, in their luxuriance of imagery, and in their graceful diction, unrivalled in any literature, will never, for you, lose their interest. Milton, blind to the external world, has laid before you his sublime visions of the invisible, and the magnificent strains in which he sings of the "Fall of Man" and of "Paradise Regained" contrast so strongly with the familiar styles of Dryden and Pope, of Addison, Scott, and Southey, and the host of writers of every character whose names are hardly less well known, that you will sometimes turn to his old, but still honored, pages when lighter literature fails to satisfy you. Our own American literature, now so rich and varied, so thoroughly characteristic, will afford you a full share of enjoyment and of profitable occupation. The finished style of Hamilton, the eloquence of Webster, and the polished orations of Everett, the plain, common-sense writings of Franklin, the elegant essays and tales of Irving, the thoughtful writings of Griswold and Lowell and of Wayland and Emerson, the nautical tales and Indian stories of Cooper, the poems of Halleck, Drake, Willis, Longfellow, Whittier, and Bryant, and of many others scarcely less famous, will give choice of companionship to suit every mood, and will offer a pleasant occupation for every hour that you can spare from business. These studies, however, are by no means to be regarded as giving you purely ornamental accomplishments, or as furnishing only entertainment for hours of leisure. You will have daily occasion to apply them usefully. The power thus acquired of expressing thought, and of stating facts with elegance, precision, and conciseness, is an important element of an engineer's success. A report made to a client, worded carelessly, expressed in vague terms and with orthography not beyond criticism, sometimes casts a dark shade over the professional reputation of a really talented, experienced, and reliable man. A specification so drawn as to be capable of double interpretation may subject one or both of the parties to the contract to serious annoyance or to great loss of time and money. You will have no excuse for such errors, and I am pleased to be able to say that I believe that you will not be compelled to plead to such an indictment.

You have given a large part of your time, during these four years of study, to the acquirement of a knowledge of the principles of ENGINEERING and to the practice of the arts which are of daily application in the practice of the profession. You have, from the beginning of your course, studied the theory of the graphic art and the geometry of machinery. You have spent such an amount of time in the drawing-room, copying well-known plans, and designing new forms of mechanism, that you have become familiar with every principle of common application in graphic construction, and with every detail of ordinary draughtsman's work. You will find this skill in sketching your plans, in making accurate drawings, and in reading the drawings of others, of daily use and of incalculable value to you. Without this power of comprehending plans existing only on paper, you would be absolutely crippled in your efforts to advance yourselves. Without the ability to sketch rapidly and draw readily and accurately, you would have the greatest difficulty in securing the prompt and thorough working of your own schemes. You have mastered the fundamental principles of applied mechanics and of mechanical construction, and have become acquainted with the nature and uses of the materials with which you are to work. You can, I presume, make a stronger lever of a built beam than could Archimedes. You have learned here probably almost as much of the characteristics of cast-iron as had Telford or Tredgold after years of professional practice. Fairbairn's lifetime of experiment and Kirkaldy's extensive researches have made you acquainted with the peculiarities of the malleable metals, and our own experiments have helped to impress old ideas and newly discovered facts upon your memories. The inventions of Cort and Neilson, and their important consequences in stimulating industry, and the splendid invention of our countryman Kelly and his British associate Bessemer, and the details of their discovery of a new metal and a new process, and the almost equally interesting and beautiful apparatus and process devised by Siemens, with their wonderful influence upon the development of the mineral resources and of every industry in all countries, are to you twice-told, but not the less interesting, tales. The growth of the mechanic arts under the stimulus of increasing intelligence and of awakened ambition as civilization has advanced, and the vast strides made during the past century, as invention has followed invention with ever-increasing frequency, have been studied with an interest that was quickened by the knowledge that the next few decades may see even greater wonders accomplished, and that to you, as well as to any other, it is possible that the honor may be accorded of worthily succeeding the great inventors and constructors of preceding generations. The water-wheel, the mariner's compass, gunpowder and nitro-glycerine, the telegraph, the chronometer, the steam-engine, the printing-press, the spinning-frame and the loom, and a thousand other inventions, seem already perfected. Yet, some one, whether man of science or working mechanic or educated engineer, none can tell, will yet rival Fourneyron, and give us better turbines, will find a means of giving us safety in navigating iron ships, will excel Frodsham in making accurate timekeepers, will give us better printing-presses, will supersede the spinning-frame and the loom, and will earn a greater fame than Watt by giving us, in some new motor, a means of approaching that theoretical efficiency to which no heat-engine has approximated. A greater than Fulton or Stevens or Stephenson will perhaps yet accomplish the last and only unfulfilled part of the prophecy made a century ago by Darwin:

> "Soon shall thy arm, UNCONQUERED STEAM! afar
> Drag the slow barge, or drive the rapid car;
> Or, on wide waving wings expanded, bear
> The flying chariot through the fields of air;
> Fair crews, triumphant, leaning from above,
> Shall wave their fluttering kerchiefs as they move,
> Or warrior-bands alarm the gaping crowd,
> And armies shrink beneath the shadowy cloud."

Who has greater reason to aspire to fame and fortune in these coming years of such noble competition than have you? The development of the natural resources of this broad land of ours will afford ample opportunity for the application of your knowledge and the practice of your art, and for the employment of every faculty, natural or acquired, that you may possess, and in whatever way your inclination may prompt, and to any extent that ambition may urge, and that your strength and endurance may permit. Take hold of the work which offers itself, never standing idle waiting for something more perfectly satisfactory, and do the work as promptly and skilfully as possible, and you will ultimately find that no man need complain that opportunities do not present themselves.

You have completed this course of study. You have prepared yourselves to go out into the great field of business life. You have acquired a fund of information such as best fits you for life's work and to enjoy life's truest pleasures. You have learned to observe. You have acquired habits of study. You have a well-trained and well-balanced judgment. You are ready to go forth and—*to begin to learn.* You stand at the foot of the ladder, in the midst of a crowd of other men, all seeking to ascend, and many, I regret to say, ready to advance themselves by throwing others down. You possess immense advantages over the great mass of your competitors in your acquired knowledge, in the habits of study, of acute observation, and of logical deduction which this education has given you. Your competitors possess the advantages of training in the rough school of the world, of a knowledge of men, of business methods, and of the rights and the wrongs of daily experience. They have had hard knocks and become callous, or have learned by dint of long practice, and by natural tact frequently, to evade them, and to push on without giving a thought to their scars. They will have the advantage of you at first, for these experiences are essential to early success. They may smile at your book-knowledge, and may sometimes even deride your more precise methods and scientific ways; but—BIDE YOUR TIME! Make yourselves masters of all the accomplishments, and seek to acquire all of the knowledge, of these rough-and-ready but untaught competitors, never refusing to give them a liberal reward from your own stores of information, should they ask it. You can afford to be patient, for this very training has fitted you to learn, even in their school. Be not obtrusive of your own knowledge, and never lose an opportunity to profit by their experience. Soon you will be able to command their respect, and it will be your own fault if you do not gain their esteem, and obtain from them cheerfully rendered and most substantial aid.

Finally, familiar with the usual methods, the practical details, and the every-day customs of the business, and possessing, besides, this splendid reserve of professional knowledge and of scientific and general education, you will find yourselves prepared to compete for the noblest prizes offered to your profession.

Remember who have preceded you: Archimedes, whose lever was to have moved the world—whose lever does move a world of industry; Michael Angelo and Leonardo da Vinci, painters and architects, as well as engineers; Stevinus of Bruges, the greatest of his time, a scientific man as well as an engineer; Galileo, whose fame as a philosopher should not be permitted to hide his connection with our profession as a teacher of mechanical principles; James Watt, the greatest mechanical engineer of the last century, who made his greater inventions sequels to scientific study and experimental research; the Stephensons, the Rennies, the Brunels, Telford and Smeaton; Napier and Elder; Maudsley and Penn; Rankine, that great representative of a class of which we expect some of you to become exponents;—all of these, in the Old World, are your predecessors. In our own country, Benjamin Thompson, who became Count Rumford, John Fitch, Oliver Evans, Fulton, and our own Stevens, whose sons so nobly sustained the fame of their father, Roebling, our adopted fellow-citizen Ericsson, Sickles, Hoe, Allen, and many others, have attained distinction, and their fame rises before you to stimulate a noble ambition and to encourage you to never-flagging efforts. Remember that the opportunities which are opened to you and to those who are to succeed you, are far more numerous than those which, grasped promptly and followed up determinedly by these great men, gave them fame and fortune; and the problems which it will fall to your lot to attack are likely to be no less important, no less difficult, and no less remunerative in reputation and pecuniary recompense, than those which gave to Newton and Rankine their fame, or to Watt and Stephenson, Telford and Brunel, that professional reputation, which they share with our own great

ountrymen. The field is ever widening, and the work is of ever-
creasing magnitude. Emulate those great pioneers, and you may
el full confidence of rich reward.

Never lose an opportunity. Men rarely succeed in life who are
eglectful of opportunities, and, in nearly all cases, those who are
ccessful can count upon their fingers the several occasions which
rmed the turning-points at which, seizing an opportunity that other
en might have overlooked or neglected, they chose the path which
d to their final success. Many men possess ability, intellectual
d physical, but yet the number who may achieve high positions is
nall. It is the taking advantage of these rare opportunities, which,
nobserved by the careless or the obtuse, are seized upon at the
ght moment and in the right manner by the watchful and the
ute, that usually secures most rapid advancement. Life is short;
reat opportunities are rare; therefore, make it a principle never to
eglect one, whether small or great; seize it promptly, and make
e most of it.

Endeavor to keep " two strings to your bow." However much en-
rossed with the work in hand, however secure apparently your
osition, however satisfactory your location, keep the fact in mind
at life is full of unexpected vicissitudes. Spare an occasional
ought to provision against loss of position, failure of business, or
ompulsory change of location. Do your work so well that you
ay feel certain that your employer or your clients cannot afford to
ispense with your services, and allow none of those about you to
xcel you. Yet be, at all times, prepared to make a new start, with
onfidence in yourself and your accumulated resources, should every-
hing fail you. To ensure this, do your work better than can those
ho may aspire to your position. Have a specialty in which none
an compete with you. Be always on the alert to make acquaint-
nces among those whose character, position, and disposition may
nable them to assist you when you find yourselves in need of as-
istance. Always assist your friends and deserving acquaintances
eartily and actively. You will thus gain the approval of your own
onscience, and will place a strong anchor to windward. The
trongest man is weaker than a child if alone in the world without
friends, and few men can say that they do not owe much of such

success as they may have attained to the aid and countenance [illegible] good friends.

Endeavor to become thoroughly acquainted with the principles and with all the details of the practice of those trades which are auxiliary to the profession of Mechanical Engineering. Ability to calculate the proper sizes of parts, to determine proportions, or even to produce neat and effective designs, is of comparatively little service if you cannot follow your design through the workshops, and indicate every step, from the first blow of the blacksmith's hammer or the first cut of the pattern-maker's chisel to the finish given each piece and the "assembling" of all parts in the erecting-shop. Do not feel satisfied until you can tell the pattern-makers how to make your pattern, the moulder how to mould it, and the founder of what mixture of metals you wish the casting made; until you can tell the blacksmith where to use the best and where to place the cheapest iron, and how to make his scarfs and welds, and how to preserve the fibre of the iron uninjured; until you can instruct an unskilful boiler-maker in the selection of his plate and in testing it, in the spacing of rivets and in the welding of a seam or the turning of a flange. Do not rest until you can take every piece of your machine as it comes from the foundry or the blacksmith's or coppersmith's shop, and fit it to its place, giving it the proper finish, in the cheapest, quickest, and most accurate manner. All this will require time, patience, and perseverance, keen observation, a good memory, and a certain amount of actual practice to bring out that natural sleight, that mechanic's "knack," that no engineer in successful practice often lacks.

In doing your work, strive to earn a perfect self-approval. Whatever the pecuniary consideration, let no task be pronounced *done* until you can feel that it is as well done as the opportunities offered and your own abilities make possible. Endeavor to make every piece of professional work of such character that you may feel conscious that it is creditable, and that you may always look back upon it with a comfortable sense of having done your very best to make it worthy of a good engineer and a credit to the profession. From first to last, work as if your sole object were to acquire a reputation for good work and to assume a leading place in your profession. You may then feel a perfect confidence that, if you earnestly seek to acquire and if you carefully cherish such a reputation for good work, honest dealing, professional skill, and general intelligence, your reputation will be very sure, in turn, to take care of you and to bring you competence, and perhaps wealth. You will, at least, certainly attain that which is better than wealth—self-respect, a quiet conscience, and the regard of all who may be brought into intimate relations with you.

And you will do your share in the work of making the extravagant words of Carlyle inapplicable here. You may remember where, in a published letter, he is said to have remarked:

"What a contrast between now and, say, only one hundred years ago! At the latter date—or, still more conspicuously, for ages before it—all England awoke to its work with an invocation to the Eternal Maker to bless them in their day's labor and help them to do it well. Now, all England—shopkeepers, workmen, all manner of competing laborers—awaken as if it were with an unspoken but heartfelt prayer to Beelzebub, 'Oh! help us, thou great lord of shoddy, adulteration, and malfeasance, to do our work with the maximum of slimness, swiftness, profit, and mendacity; for the devil's sake. Amen.'"

This seems absurd extravagance, yet there is too much truth in it. But I believe that the world moves forward—never backward—and that we are continually approaching better days. Take for your motto, "*Fortiter, fideliter, feliciter,*" and, doing your duty bravely, faithfully, and successfully, others will profit by your good example, and you will help us all onward while earning your own recompense.

Make the most of your resources. The greatest skill is frequently exhibited by the engineer in doing inexpensive work. In some cases the production of elaborate designs and graceful forms, the use of the best materials, and the employment of fine workmanship and the adoption of a beautiful finish, are not only allowable but incumbent upon you, and such construction is at once truly economical and most creditable. In other instances, the highest art is shown in accomplishing a given object at the least expense compatible with safety. Even rude devices, cheap materials, rough workmanship, and entire absence of ornament and finish, are evidences, at times, of the ability of the engineer to accommodate himself to circumstances and to accomplish large results with small means. The character of your work in this respect should be determined by the nature of the problem itself, by the means at hand, and by the value of capital. Where capital is plentiful and cheap, and where labor and good materials are plentiful and cheap, it would be inexcusable to design and to construct, in important work, anything but the best work that you are able to produce, using the best material and demanding the best of workmanship. Where capital is difficult to obtain, materials ill-supplied, and labor expensive, and where the structure is a temporary one, the really good engineer will pursue quite an opposite course. To build cheap railroads and machinery in Great Britain, where capital is worth but four or five per cent. per annum, and labor four or five shillings per day, as we build them in our Western and Southern States, where money costs ten per cent. and labor is worth twice as much as abroad, would be extremely unwise. If it were stipulated that all new roads in the United States should be given easy grades, curves of large radius, or a straight track, well ballasted, with cut-stone masonry and iron bridges, and furnished with station-buildings and permanent structures of stone and brick; if it were prescribed that they should be provided with an ample supply of the best rolling-stock, heavy locomotives, cars fitted with all the most recent improvements, and with every convenience known on old and wealthy roads, we should have no new roads, and the country would remain undeveloped. A machine designed for temporary use should be made at the least possible cost at which it will certainly serve its purpose. A machine which is expected to work well until worn out, and then to be replaced by another, should be made of good materials and in the best manner. Where it is anticipated that the machine will be superseded by another of improved design before it can be expected to become useless by wear, it is a waste of means to build it with a view to durability simply, and regardless of expense. It is for this reason that the light, cheap, but equally efficient machinery built by our mechanics for some branches of textile manufactures, and some of our lighter tools, are better, on the whole, than the heavier and more expensive machinery supplied by foreign builders. Improvements follow each other with such rapidity that it becomes necessary sometimes to throw out this finely-built machinery before it is half worn out. This difference in first cost is thus simply so much capital thrown away. Here, as in many cases that will arise, a good judgment, a strong, practical common-sense, guided by experience and enlightened by acquired knowledge, is your only reliance in determining where lies the golden mean.

Make the interests of your client your own. Let me remind you of the bad policy, of the wrong of which you would be guilty, were you in any case to permit the apparent interests or the wishes of a client to induce you to adopt a plan which your judgment, your knowledge, and your experience condemn. On the other hand, never permit your own interests to dictate a course obviously opposed to the best interests of the client who has entrusted his business to you; and never pursue a line of policy and action of which you know the results will fail to meet his expectations fully in every particular. Present to him every reason, *pro* and *con;* explain the case fully; and if his interests and your own are not identical and cannot be perfectly harmonized, state the matter frankly and courteously, and decline the work. Such a course will always prove to be most correct and most satisfactory in all respects. You will retain the esteem and good-will of your client, and the small, or even the large, amount of money surrendered will have a full equivalent in the gain of a greater self-respect.

Be guided always, but never ruled, by precedent. Mr. Lowe, in an address at the London University, says:

"The man who prefers custom to law announces a principle which would stereotype every abuse, and substitute the blind guesses of barbarism for the clear, well-considered conclusions of a civilized age."

And this is as true in engineering as in ethics. While it is probably true that your fathers are wiser than their sons, it is also probably true that they are also wiser than were your grandfathers, and that you will properly be expected to become at their age wiser than they. Therefore, be always ready to accept what seems, all things considered, best in principle and in practice, without a prejudice arising from its novelty. Study newly discovered laws, and examine every new fact in a fair-minded spirit, and be ready to take full advantage of every evident improvement suggested to you. Respect traditional custom and common practice. They are probably founde d upon good reasons and the teachings of experience; but be neith er hampered nor blinded by them.

Be radical in theory, but extremely conservative in practice. I wou ld warn you against too free indulgence in experimental practic e. Your client's money should never be risked in even the most pro nising of new schemes, except with the most thorough understandi g on his part of the uncertainty involved, and except where you are as fully absolved of all blame, aside from an error of judgment, in ca se of failure. You will find men on all sides following the seducti ve paths of invention and experiment. Watch them when you ca n. Keep yourselves well informed of all such work in those directio ns in which improvement is desirable, and stand ready to seize a nd to utilize every *proven* success. Be exceedingly wary, howeve r. Even the best of men have been misled by such absurdities as pe rpetual motion and kindred schemes, ingeniously presented a nd curiously disguised. The greatest deceptions are those which see m simplest and easiest of investigation. Yet do not hesitate to embar k your own means in promising experiment or in the development of inventions if you find yourself well able to do so; never forge tting, however, that the perfecting of a new design and the openi ng of a market is usually a matter of vastly greater expense than at fir st estimated.

Help the inventor whenever an opportunity offers to do so wi th propriety and to do so effectively. Lend him your most effective ai d. Encourage him when his schemes appear to promise well. Nev er refuse to assist him in detecting fallacies or by exposing the erro rs into which his enthusiasm may have seduced him. Respect hi m and honor him as one of a class whose services to you and to t he world are beyond estimate or recompense, and who are rare ly rewarded for a tithe of their freely expended time, means, a nd health. You will meet schemers, dreamers, and ignorant pretende rs every day. Do not hesitate to expose them to themselves, and, if necessary, to the world. But, as you demand the respect of yo ur fellow-men, and expect credit for good intent and earnest attenti n to duty, see that you yield the same respect and accord the sa e credit to every honest inventor. Remember that he is a brother of Savery and Newcomen, of Watt and Evans, the inventors of t e steam-engine, a colleague of Wheatstone and Morse, who gave us the telegraph, and of Stephenson, who made the railroad a daily convenience; that he is of the same race with Guttenberg, who gave us types, and of Hoe, who, with his wonderful printing-press, made possible the modern newspaper and that multiplication of books of "which there is no end." He is of the same blood with Arkwright, who gave us the loom, and with Howe, who responded to the touching "Song of the Shirt" by producing the sewing-machine. He is one of a noble army of the truest benefactors of the human race. Respect the inventor, though his hand may be hard and soiled, his clothing worn, his manners rude, and his language ill-chosen. He is one whose name may be remembered long after you and I and all of us who pride ourselves upon fortune of birth, property, breeding, or education have passed away and are quite forgotten.

You will be called upon in your business and in your social life to meet all classes of men, and you will, like all other men, often serve, and will often have occasion to accept the services of others.

In your intercourse with those whom you are to serve, exhibit respect and courtesy, without unseemly deference; be straightforward in act and in word; promise only what you can certainly perform, and make your agreement in such definite form that no misunderstanding can arise, and so that each party to the bargain shall be distinctly bound to render an equivalent for what he receives.

In dealing with those who render you service, never forget that respect which is the rightful due of every honest man. Use few words; make your bargain in a generous spirit; offer rather more than the current market price, trusting to your care in selecting employees for full remuneration. Give no man cause of complaint, and never submit to the slightest evident attempt at extortion or fraud.

Do not give up your studies, however pressed by business, but see that you make your foundations deep and solid by future acquirements. I cannot do better than to commend to you the words of President Eliot of Harvard University, who says:

"For ambitious young men, no exhortation to lay broad and deep foundations in youth is so effective as the spectacle of promising careers ruined, and great opportunities of distinction and usefulness lost, mainly for lack of thorough education. The greater the natural ability of conspicuous actors in such scenes, the more pitiable does it seem that they should fail at fifty for lack of knowledge which they might easily have acquired at twenty-five. The surest way to succeed in any profession, military or civil, scientific or learned, is to get, in early life, the best and completest training for it which the country affords."

Take care of your health. Keep this wonderful machine which we call the body—this mechanism which is at once the domicile and the servant, the transporter and the feeder, of the soul and of the mind—in the highest state of efficiency. Study the laws of health, and obey them as conscientiously as the laws of morals or of civil and social duty. A mind diseased is often but the exponent of a body diseased. Restore the body to health, and the mind will often be restored its activity and its intellectual and even moral strength. You can neither enjoy life nor do your full duty to either God or man if your body, bones, and muscles, as well as nerve and brain, are not in perfect health. Remember that Nature punishes every fault of ignorance and of carelessness with absolute certainty and without mercy, as she punishes every deliberate violation of her laws made with full knowledge and with "malice prepense." The sins of youth are visited upon old age, and those of parents upon "children and children's children unto the third and the fourth," and perhaps to many succeeding generations. This is an all-important matter, and a long life, full of good works, can never be preceded by a course of conduct other than that which we all know to be essential to the preservation of health of body and purity of soul. Even moderate smoking weakens the vital powers; the slight excesses of the moderate drinker shorten his life; and every ounce of food uncalled for by the stomach, every innutritious article of diet taken into the body, taxes the system. Our habits of life and our methods of work determine the state of our health, and give us either the pangs and worries of dyspepsia, with lax muscles, feeble nerves, weakness of character, and powers of mind easily overtaxed; or they give us hard, wiry muscles and firm flesh, good digestion, a power of endurance of physical labor, and of mental as well, a fresh, active brain, with accurate perception, clear judgment, good memory, a pleasant frame of mind, and the power of doing a day's work with satisfaction to ourselves and to those who are about us, and of feeling fresh at the end of it. Therefore, care for your health. It were far better that this machine should wear out than that it should rust out. A man had better die young of overwork than live a long life without accomplishing anything, and finally die of old age without having done a man's work in the world. But it is best, by far, to keep the machine at work steadily and efficiently, with every sliding part and revolving journal well lubricated, and with every member well protected against oxidation, thus securing a long period of usefulness and a maximum length of life and amount of work performed. It is best, by far, that this human mechanism be kept at work steadily and regularly, without haste, without faltering, with every muscle in good order, the digestive functions working properly, the circulation regular and strong, the brain and nervous system well nourished and kept in training, and a long life thus ensured, full of usefulness—a maximum value given to the lifetime thus prolonged. Keep always in mind the splendid motto on Goethe's seal:

"Ohne Haſt, ohne Raſt, wie die Sterne!" *

President Porter of Yale College gives you terse and sound advice in regard to your conduct and bearing as men:

" Young men," said he to his pupils, " you are the architects of your own fortunes. Rely upon your own strength of body and oul. Take for your star Self-reliance. Inscribe on your banner: Luck is a fool; pluck is a hero.' Don't take too much advice; keep at your helm, and steer your own ship, and remember that the great art of commanding is to take a fair share of the work. Think well of yourself. Strike out. Assume your own position. Put potatoes in a cart over a rough road, and the small ones go to the bottom. Rise above the envious and the jealous. Fire above the mark you intend to hit. Energy, invincible determination, with a ight motive, are the levers that move the world. Don't drink; on't chew; don't smoke; don't swear; don't deceive; don't read ovels; don't marry until you can support a wife. Be in earnest; e self-reliant; be generous; be civil. Read the papers. Adver-

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* Without haste, without rest, like the stars.

tise your business. Make money, and do good with it. Love your God and your fellow-men; love truth and virtue; love your country, and obey its laws."

In character, I would urge you to seek to become what Sir Philip Sydney was—honest, brave, quick of wit, of kindly and gentle disposition, of noble and generous impulse, combining a sedate wisdom with all the chivalry of a romantic age; hungering for knowledge, thirsting for adventure, fresh in heart, with a tenderness and a child-like simplicity such as is to-day too rarely even respected, still less emulated. All of these qualities united to make a character not free from fault, but yet, in its *ensemble*, most admirable and most worthy of study and of imitation. If you can unite with all this something of that sterner but not less lovable character which is ascribed to the Puritan of that period, you will not respect yourselves less, and will be none the less honored by your fellow-men. "His aim," says an historian,* "was to attain self-command, to be master of himself, of his thought and speech and acts. A certain gravity and reflectiveness gave its tone to the lightest details of his daily converse with the world about him." "His life was orderly and methodical, sparing of diet and of self-indulgence. He rose early; he was never at any time idle, and hated to see any one else so." Be like Colonel Hutchinson, who "had a loving and sweet courtesy to the poorest," and who "never disdained the meanest nor flattered the greatest."

Do you remember what Beaumont and Fletcher say in the epilogue to "Honest Man's Fortune"?

"Man is his own star, and the soul that can
Render an honest and a perfect man
Commands all light, all influence, all fate;
Nothing to him falls too early or too late.
Our acts our angels are, or good or ill,
Our fatal shadows that walk by us still."

Preserve a firm faith in your own judgment, but weigh without prejudice the facts presented to your own observation and the arguments offered by others. Cultivate self-respect, conscientiousness, and persistence. Prepare yourself to say with Peter Cooper, who, on his eighty-third birthday, met his many friends and received well-deserved congratulations: "I have always recognized that, while the object of business is to make money in an honorable manner, the object of life is to do good." Make this sentiment your own. Then, "with malice towards none" and "with charity for all," wend your way steadily, bravely, quietly, and happily through life, with full confidence that, at the end, you may look back with a glorious feeling of peaceful satisfaction upon long years of public and private usefulness, of well-earned honors, and of truest happiness.

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* Green, J. R., "History of the English People."

And now, for the many friends who part with you here, temporarily as we hope, and in behalf of my colleagues, and for myself, who have watched your course during these four years with all of that mingled anxiety and satisfaction which arises from a sense of the responsibility thrown upon the exponent of a new method and the representative of a new professional school, and from the gradual advance of our experiment to a happy and most encouraging result, I must declare this work concluded, and must, for myself and all, bid you farewell. Yet before saying this last word, let me remind you that, going out into the world from this quiet, happy home, where you have spent so long a time in preparation for the great work which awaits every one on reaching man's estate, you will not, we hope, consider yourselves entirely dissevered from all these old associations, from your old friends and college mates, or from your ALMA MATER. We shall hope to meet you at these annual celebrations in succeeding years, to exchange pleasant greetings, to learn of your strivings and of your successes, to listen to your story of good works well rewarded, and to show you, in our turn, the growth of the college, the improvement of methods, and an unintermitted elevation of the standard of scholarship and of professional attainments. Even here, remember, you can help us. You are a body of standard-bearers, sent out to lead a small but growing army of practically scientific men. You will aid to make for your teachers and for the college just such a reputation as you shall make for yourselves. You have a great, almost an intimidating, responsibility in the proper use of this power for good or for evil. See, I beg of you, that your efforts are effective in upholding this exponential enterprise, and lose no opportunity to repay, so far as you are able, the obligations here incurred. Send us manly, intelligent, earnest, active-minded, and ambitious students, who will not require to be reminded of the only rule of this institution, unwritten though it is: "Every gentleman here is required to be a student; and every student is expected to be a gentleman." Divert into these collections whatever you may find and secure that shall promise to be valuable to such students, and, sustaining this great enterprise by every moral and social aid, and by every material contribution that it may be in your power to obtain for it, do unto those who are following you as others have done unto you. Such an institution cannot have too many or too earnest and powerful friends. It must always look to its own Alumni for its most sincere and its most reliable supporters. Be yourselves always worthy of the name of an ALUMNUS OF STEVENS, and aid all of our friends in their efforts to make the college the pride of its Alumni. Keep us all in your memories, as we shall preserve you in ours, and do not forget that, wherever fate may lead you, friends are here sympathizing with you in your trials, taking pride in your successes, and ever watching your progress in an honorable career.

And now I must say the last but yet cheering word. For all who have here gathered to meet you, I give you this, our formal

FAREWELL!

Plan of the Institution.

THE plan of instruction pursued is intended to be such as may best fit young men of ability for leading positions in the department of Mechanical Engineering, and in scientific pursuits.

With this view:

1. It affords a thorough training in Mathematics, in so far as they are useful means of investigation and of work, and not themselves the ends and objects of labor.

2. A department of Belles-Lettres furnishes the means of cultivating a literary taste and facility in the use of language, which are as desirable in the engineer and man of science as in the classical student.

3. The French and German Languages form an essential part of the course of instruction. They are indispensable to the engineer and man of science as the vehicles of a vast amount of information, and also as affording that kind of mental culture which mathematical and physical science, if followed exclusively, would fail to supply.

4. The subjects of Chemistry and Metallurgy are thoroughly taught, with all the modern appliances and working laboratories.

5. Arrangements of an unusually perfect character have been made to give a thorough practical course of instruction in Physics, by means of physical laboratories, in which the student is guided by the professor of Physics in experimental researches bearing upon the subjects of his special study.

Thus the student will experimentally study those methods of making measures of precision which are used in all determinations in Physics; he will measure for himself the tension of steam at various temperatures, and construct the curve showing their relations; he will determine the electrical resistances of several conductors and insulators, and so on through the subjects of Physics.

6. The subject of Mechanical Drawing forms a separate department, to which much time is given.

The course comprises the Use of Instruments and Colors, Descriptive Geometry, Shades, Shadows, and Perspective, and the Analysis of Mechanical Movements—the principles involved being applied in the construction of plans.

7. The subject of Mechanical Engineering, including theory and practice in the construction of machines, forms a distinct department, under the charge of a professor experienced in the practical relations of his subject, who will devote his entire attention to the branch.

STEVENS INSTITUTE OF TECHNOLOGY.

as long. Thus would be effected a saving of $880 per mile* in the seve years, on sleepers alone. In the United States are 33,908·6 miles railroad.† The whole saving on these lines would be $29,839,568, c upwards of $4,262,795 per annum.

Again, English engineers deride American wooden railway bridges Eight years is their average duration.‡ Creosote them and they ar good for double or treble that time.§ For ordinary railroad purposes they cost $40 per linear foot.‖ The use of Bethell's process would effect a great saving on such a line as the Grand Trunk Railway, whose wooden bridges measure 9355 feet upon the Montreal and Portland division alone.¶ Further illustrations of the importance of preserving timber from decay seems unnecessary. Let us proceed to the discussion of this desirable object.

In situations so free from moisture that we may practically call them dry, the durability of timber is almost unlimited. The roof of Westminster Hall is more than 450 years old. In Stirling Castle are carvings in oak, well preserved, over 300 years of age. Scotch fir has been found in good condition after a known use of 300 years,** and the trusses of the roof of the Basilica of St. Paul, Rome, were sound and good, after 1000 years of service.†† After these well attested examples of preservation, the further consideration of wood in this state seems unnecessary.

Wood constantly wet in fresh water is quite as durable. Piles were dug from the foundations of old Savoy Palace, in a perfectly sound state, after having been down 650 years. The piles of old London Bridge were found sound and perfect 800 years after they were driven.‡‡

While the acidity of bog-water retards decay, it seems to us that part of the preservative property attributed to the stagnant liquids should be ascribed to the salts of metals or alkaline earths held in solution, and deposited among the woody fibres.

In the above situations, the action of natural agents cannot be improved. But in certain other conditions, man must resort to preservative processes to secure permanence of structure. For convenience of discussion we have introduced the following classification:

1. When wood is damp we have to guard against dry rot.
2. When wood is alternately wet and dry we have to guard against wet rot.
3. When wood is constantly wet in sea-water we have to guar against teredo navalis and limnoria terebrans.

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[*] Five cents, at seven per cent. compound interest, amounts, in seven years, t eight cents. 50 cents — 8 cents = 42 cents saved *on each sleeper* at the end of seve years. $0·42 × 2112 = $887·04 saved per mile in seven years.

[†] De Bow's *Review*, February, 1866, page 207.

[‡] *Civil Engineer's Journal*, vol. xxiv., page 282.

[§] "A properly constructed railway bridge of suitable materials may be ful relied on for twenty years."—*Journal Franklin Institute*, vol. xxxvi., page 1.

[‖] *Civil Engineer's Journal*, vol. xxiv., page 282.

[¶] *Journal Franklin Institute.*

[**] The *Builder*, vol. ii., page 638. [††] Ibid., p. 616. [‡‡] Ibid., p. 616.

[§§] *Civil Engineer's Journal*, vol. xxi.

1. *Wood in Damp Situations.*—When unseasoned wood is surrounded by dead air, it very rapidly decays, fine fungous growths extending through every part. After the rot has begun, the mere contact of decayed and sound wood seems sufficient to ensure, by a catalytic action, its spread through the latter. This has probably led some observers to their conclusions, that the accompanying parasitic plants, Merulius lachrymans (or L. vastator) and Polyporus hydridus, cause the decay. But the highest authorities now regard these growths as accessory, and beginning only after a suitable habitat has been prepared for them.* Thus the fungus acts the part of a scavenger and converts corrupt matter into new forms of life. The presence in the timber of the fungi spores is easily explained. The researches of Pasteur show that atmospheric dust is filled with minute germs of various species of animals and plants, ready to develop as soon as they fall into a congenial locality. He concludes that all fermentation is caused by the germination of such infinitesimal spores.† That they elude observation, does not seem strange, when we consider that some infusoria are only $\frac{1}{24000}$ of an inch in length.‡ Admitting that they are only ten times the linear dimensions of their germs, the latter will be $\frac{1}{240000}$ of an inch long. But with the best microscopes we cannot perceive objects measuring less than $\frac{1}{80000}$ of an inch. These germs might find their way into the growing plant through both roots and leaves. The whole tree is thus filled with the seeds of decay, awaiting suitable conditions to spring into growing organisms. The prolonged vitality of spores, made necessary by this theory, cannot be a serious objection, when we remember the vigor of the "mummy wheat," and the unknown plants which start from the earth raised from deep excavations. Indeed, time, even when measured by centuries, seems hardly to affect the vitality of vegetable germs.

But what prepares timber for the germination of the fungi spores? Probably fermentation of the juices and semi-solids of the moist wood. For fermentation, five conditions are necessary,§ viz: 1. Presence of water. 2. Temperature from 40° to 110° Fahr. 3. Presence of a ferment. 4. Presence of a fermentable body. 5. Exposure to the atmosphere.

Three of these conditions almost always prevail. Very rarely, if ever, can we maintain the temperature of any timber construction below

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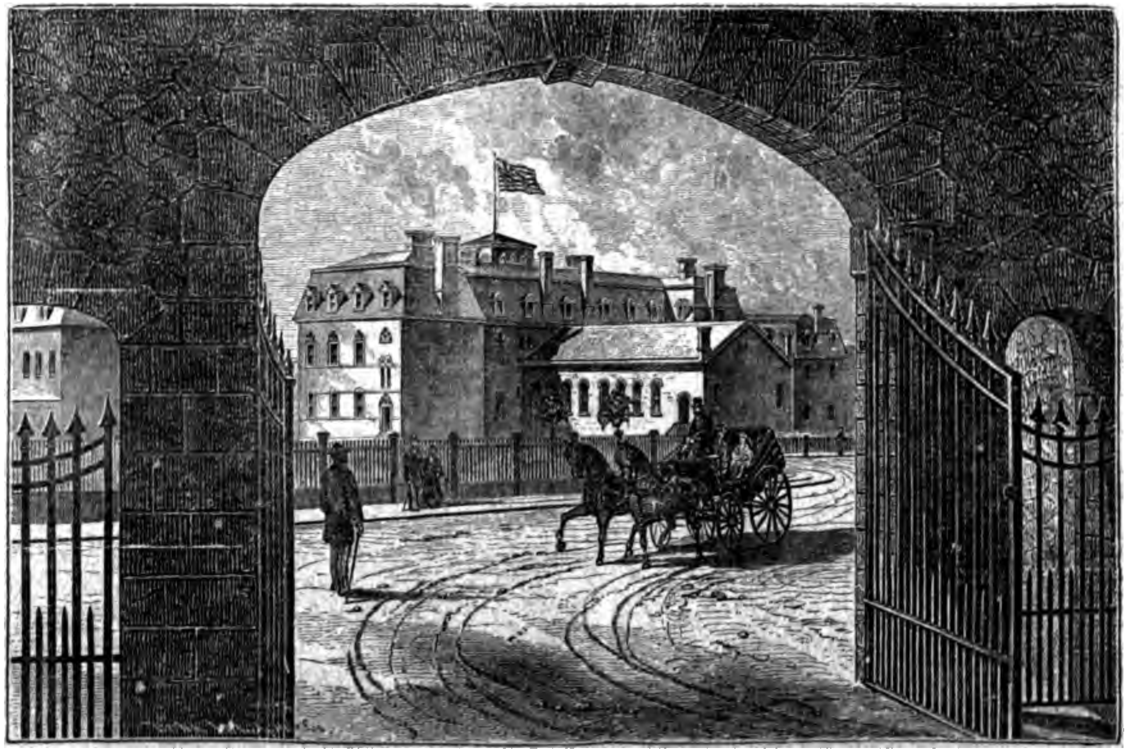
* "There is no reason to believe that fungi can make use of organic compounds in any other than a state of decomposition."—Carpenter's *Comp. Physiology*, page 165. (See also *Encyclopædia Britanica* on this subject.)

† "Powders suspended in the air are the exclusive origin, the first and necessary condition of life in infusions, in putrecible bodies, and in liquids capable of undergoing fermentation."—See translation of Pasteur's experiments in vol. xxxii.,gae p 9 of *American Journal of Science.*

‡ "Some infusoria are not more than $\frac{1}{24000}$ of an inch in diameter, and if we suppose the spores to be only $\frac{1}{10}$ of the parent's linear dimensions, there must be an incalculable amount of germs no larger than $\frac{1}{240000}$ of an inch in diameter. Since, according to Sullivant and Wormley, vision, with the most powerful microscopes, is limited to objects of $\frac{1}{80000}$ of an inch, we need not be surprised that we do not always see the floating germs of animals and plants."—Note by the translator of Pasteur's researches, *American Journal of Science*, vol. xxxii., page 9.

§ Notes on Prof. A. B. Prescott's *Lectures on Organic Chemistry* in the University.



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PRESERVATION OF WOOD

IN

DAMP AND WET SITUATIONS.

By H. W. Lewis, University of Michigan.

GRADUATING THESIS.

From the Journal of the Franklin Institute.

·ervation of Wood in Damp and Wet Situations. By H. W. Lewis, University of Michigan.

GRADUATING THESIS.

From the Jounal of the Franklin Institute.

Io introductory apology for the theme of this paper is judged ne- ıary. A few plain statements will show that the subject is one of ; though unheeded importance.

'he annual drain which is exhausting our forests is startling when remember the vast areas of our country utterly destitute of tim- —when we learn, for instance, that "upon the 55,000 square miles [llinois, there grows not a single pine large enough from which to ıion a board.* Statistics show that, in 1865, above 5,000,000,000 of lumber, 2,000,000,000 of shingles, and 900,000,000 pieces of ı were sold in Chicago alone.† Michigan and Wisconsin almost en- ly supply that market. 6000 feet of pine lumber per acre is an rage yield.‡ No formal calculation is necessary to show us that, h the present demand, a single generation will exhaust the supply se States can afford.

3ut the consumption increases in a rapid ratio. It has already ıed the prices. Clear lumber sold for $18 per thousand in 1855, for l per thousand in 1860, and for $45 per thousand in 1865.§ And owing close on Chicago, in this trade, are Albany and Pittsburgh.‖ mprovidence will soon, we fear, make us as dependent on foreign plies of timber as is England, who has already granted numerous ents for processes promoting the durability of the lumber every ghtened nation must have.

hall we employ those processes whose utility experience has de- ıstrated? Self-interest returns but one answer. But in American way management, self-interest seems to be disregarded. While the 'age life of English railway sleepers is fifteen years, that of Ame- n sleepers is only seven years.¶ Allowing 2112 sleepers per mile, ifty cents each,** $1056 per mile of American railroad *decays* y seven years. Thoroughly impregnate those sleepers with sul- e of copper, at a cost of five cents each, and they would last twice

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Hunt's *Merchant's Mag.*, Feb., 1866, page 105.

Lumber, 5,089,033,033 feet; shingles, 3,560,093,212; lath pieces, 938,297,743. nt's *Merchant's Mag.*

' An average estimate of the product of lumber of all the pine lands in the is 6000 feet to the acre. Some sections will overrun, some fall short, of this nt." * * * "Seven years will exhaust all the pine lumber within five of any of the navigable rivers."—*The Pine Lands and Lumber Trade of Mi- n*, page 4.

Hunt's *Merchant's Mag.*, Feb., 1866, pages 106 and 107. ‖ Ibid., p. 105.

New American Cyclopædia, vol. xiii., page 734.

Scientific American, February 17, 1866. Also Col. Berrien's (Chief C. E. of R. R.) estimate of their cost for the past two years on the "Michigan Central oad."

of Boston salted his ships with 500 bushels of the chloride, disposed as an interior lining, adding 100 bushels at the end of two years.[*] Such an addition of dead weight, (35,000 pounds in this case,) is sufficient objection to a procedure which has other great disadvantages.

The unpleasant odor of creosote is greatly against its use upon lumber for dwellings, and Bethell's process, therefore, is not described here, although the most satisfactory known. Pyrolignite of iron is offensive and also highly inflammable. The affinity of the chlorides for water keeps the structure into which they are introduced wet; besides, they corrode the iron-work. Sulphate of copper is free from these objections, and is, at present, cheaper than the chlorides.[†] Therefore, *for protecting wooden structures against dry rot* in damp situations, like mines, vaults, and the basements of buildings, *sulphate of copper seems preferable, and Hewson's or Boucherie's method of injecting it cheaper and more expedient, according as the timber is short or long.*

II. *Wood alternately wet and dry.*—The surface of all timber exposed to alternations of wetness and dryness, gradually wastes away, becoming dark-colored or black. This is really a slow combustion, but is commonly called wet rot, or simply rot. Other conditions being the same, the most dense and resinous woods longest resist decomposition. Hence the superior durability of the heart-wood, in which the pores have been partly filled with lignine, over the open sap-wood, and of dense oak and lignum-vitæ over light poplar and willow. Hence, too, the longer preservation of the pitch-pine and resinous "jarrah" of the East, as compared with non-resinous beech and ash.

Density and resinousness exclude water. Therefore our preservatives should increase those qualities in the timber. Fixed oils fill up the pores and increase the density. Staves from oil barrels and timbers from whaling ships are very durable. The essential oils resinify, and furnish an impermeable coating. But pitch or dead oil possesses advantages over all known substances for the protection of wood against changes of humidity. According to Professor Letheby,[‡] dead oil, 1st, coagulates albuminous substances; 2d, absorbs and appropriates the oxygen in the pores, and so protects from eremacausis; 3d, resinifies in the pores of the wood, and thus shuts out both air and moisture; and, 4th, acts as a poison to lower forms of animal and vegetable life, and so protects the wood from all parasites. All these properties specially fit it for impregnating timber exposed to alternations of wet and dry states, as, indeed, some of them do, for situations damp and situations constantly wet. Dead oil is distilled from coal-tar, of which it constitutes about ·30, and boils between 390° and 470° Fahr. Its antiseptic quality resides in the creosote it contains. One of the components of the latter, carbolic acid (phenic acid, phenol) $C_{12} H_6$

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[*] *American Journal of Science*, vol. ii., p. 17.

[†] Price of sulphate of copper per pound 11¾ and 12 cents; sulphate of zinc 8 and 12 cents; chloride of zinc $1·60 and $1·75; chloride of mercury, $1·08 and $1·10. —From *Druggist's Circular*, June ,1866.

The price paid for chloride of zinc by the Michigan Central Railroad Company, two years ago, was 6 cents per pound.—*Auditor's Office, M. C. RR. Co.*

[‡] *Civil Engineer's Journal*, vol. xxiii., page 216.

O_2,[*] the most powerful antiseptic known, is able at once to arrest the decay of every kind of organic matter.[†] Prof. Letheby estimates this acid at ½ to 6 per cent. of the oil. Chrysilic acid C_{14} H_8 O_2, the homologue of carbolic acid, and the other component of creosote, is not known to possess preservative properties.

Bethell's process[‡] subjects the timber and dead oil, enclosed in huge iron tanks, to a pressure varying between 100 and 200 pounds per square inch, about twelve hours. From eight to twelve pounds of oil are thus injected into each cubic foot of wood. Lumber thus prepared is not affected by exposure to air and water, and requires no painting.[§] A large number of English railway companies have already adopted the system.[||] Eight pounds of oil per cubic foot is sufficient for railway sleepers.[¶]

The cost of "creosoting," as this process is sometimes called, was given in 1855, by Ronald and Richardson, at somewhat less than four pence per cubic foot,[**] in England. At one shilling per gallon,[††] the price at which dead oil was obtainable in England in 1863, four pence per cubic foot would, we presume, be sufficient.

A process recently patented, and described in the *Scientific American*, February 17, 1866, proposes to introduce highly heated oleaginous vapors among the timber, confined in an iron tank. The patentee[‡‡] hopes, that as fast as the moisture is expelled from the wood, the vapor will take its place. Whether this substitution would not soon arrest itself, should it even commence, is in our mind a debatable question.

While an external application of coal-tar promotes the preservation of dry timber, nothing can more rapidly hasten decay than such a coating upon the surface of green wood. But this mistake is often made, and dry rot, instead of wet rot, does the work of destruction.* The reason must appear from what has been said on dry rot. Carbonizing the surface also increases the durability of dry, but promotes the decay of wet, timber. Farmers very often resort to one of the latter methods for the preservation of their fence-posts. Unless they discriminate between green and seasoned timber, these operations will prove injurious instead of beneficial.

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[*] "Creosote from coal undoubtedly contains two homologous bodies, C_{12} H_6 O_2 and C_{14} H_8 O_2, the first being carbolic and the second cresylic acid."—Ure's *Dict. of Arts, Manu., and Mines*, vol. ii, p. 628.

[†] "I have ascertained that adding one part of carbolic acid to five thousand parts of a strong solution of glue will keep it perfectly sweet for at least two years. . . . . Hides and skins, immersed in a solution of one part of carbolic acid to fifty parts of water, for twenty-four hours, dry in air and remain quite sweet."—Prof. Crace Calvert, *Ann. Sc. Discov.*, 1865, p. 55.

"Carbolic acid is sufficiently soluble in water for the solution to possess the power of arresting or preventing spontaneous fermentation. Saturated solutions act on animals and plants as a virulent poison, though containing only five per cent. of the acid."—*Cio. Eng. Jour.*, vol. xxii., p. 216.

"Parasitic and other worms are instantly killed by a solution containing only one-half per cent. of acid, or by exposure to the air containing a small portion of the acid. . . . . By examining the action on a leaf, we find the albumen is coagulated. All animals with a naked skin, and those that live in water, die sooner than those that live in air and have a solid envelope."—Dr. I. Lemaire *Ann. Sc. Discov.*, 1865, p. 238.

[‡] Ronald and Richardson's *Technology*, p. 789.

[§] Ure's *Dict. of Manu. and Mines.*

[||] The Great Western, North-Eastern, Bristol and Exeter, Stockton and Darlington, Manchester and Birmingham, and London and Birmingham.—Ure's *Dict. of Manu. and Mines.*

[¶] *Jour. Frank. Inst.*, vol. xliv., p. 275.

[**] *Chemical Technology*, p. 787.

[††] Dr. J. G. Ashby in the *London Mechanic's Magazine*, July, 1862. He says, "Crude carbolic acid can be obtained for one shilling," but undoubtedly means dead oil.

[‡‡] Louis S. Robbins, New York City.

In this connection, we remark, that inverting a post from the position in which it grew, is by some supposed to retard decay. According to the President of the "Northern Architect's Association," England, "the *valves*" close against moisture ascending through the ducts from the earth into the post.† But, according to Gray, thin places only separate contiguous ducts. Fluids can pass through them in *one* direction as well as in the *other*. When age obliterates these thin mediums, nothing opposes the flow upward or downward. Furthermore, the passage of fluids through wood is not confined to ducts: it takes place on all sides of them as well. In face of these facts, very careful experiments will be requisite to convince us that a post is more durable in the inverted than in the normal position.

III. *Timber constantly wet in salt water.*—We have not to guard against decay when timber is in this situation. Teredo navalis, a mollusk of the family Tubicolària, Lam., soon reduces to ruins any unprotected submarine construction of common woods. I quote from a paper read before the "Institute of Civil Engineers," England, illustrating the ravages of this animal:

"The sheeting at Southend pier extended from the mud to eight feet above low-water mark. The worm destroyed the timber from two feet below the surface of the mud to eight feet above low-water mark, spring-tide; and out of 38 fir-timber piles and various oak-timber piles, not one remained perfect after being up only three years."‡ Specimens of wood, taken from a vessel that had made a voyage to Africa, are in the museum, and show how this rapid destruction is effected.

None of our native timbers are exempt from these inroads. Robert Stephenson, at Bell Rock, between 1814 and 1843,§ found that greenheart oak, beef-wood, and bullet-tree were not perforated, and teak but slightly so. Later experiments show that the "jarrah" of the East, also, is not attacked.‖ The cost of those woods obliges us to resort to artificial protection.

The teredo never *perforates* below the surface of the sea-bottom,¶ and probably does little injury above low-water mark. Its minute orifice, bored across the grain of the timber, enlarges inwards to the size

* According to Col. Berrien, the Michigan Central Railroad bridge, at Niles, was painted, *before seasoning*, with "Ohio fire-proof paint," forming a glazed surface. About five years after, it was so badly dry rotted as to require rebuilding.

† The *Builder* for 1866, p. 79.

‡ *Civ. Eng. Jour.*, vol. xii., p. 382.

§ Ibid., vol. xx., p. 16.

‖ The *Builder* for 1862, p. 511.

¶ *Civ. Eng. Jour.*, vol. xx., p. 17.

of the finger, and soon becomes parallel to the fibre. The smooth circular perforation is lined throughout with a thin shell which is sometimes the only material separating the adjacent cells. The borings undoubtedly constitute the animal's food, portions of woody fibre having been found in its body.* While upon the surface only the projecting siphuncles indicate the presence of the teredo, the wood within may be absolutely honey-combed with tubes from one to four inches in length.

It was naturally supposed that poisoning the timber would poison or drive away the teredo, but Kyan's, and all other processes employing solutions of the salts of metals or alkaline earths, signally failed. This, however, is not surprising. The constant motion of sea-water soon dilutes and washes away the small quantity of soluble poison with which the wood has been injected. If any albuminate of a metallic base still remains in the wood, the poisonous properties of the injection have been destroyed by the combination. Moreover, the lower vertebrates are unaffected by poisons which kill the mammals. Indeed, it is now known that certain of the lower forms of animal life live and even fatten on such deadly agents as arsenic.†

Coatings of paint or pitch are too rapidly worn away by marine action to be of much use, but timber, thoroughly creosoted with ten pounds of dead oil per cubic foot, is perfectly protected against teredo navalis. All recent authorites agree upon this point. In one instance, well authenticated, the mollusk reached the impregnated heart-wood by a hole carelessly made through the injected exterior. The animal pierced the heart-wood in several directions, but turned aside from the creosoted zone.‡ The process and cost of "creosoting" have already been discussed.

A second destroyer of submarine wooden constructions is limnoria terebrans, (or L. perforata, Leach,) a mollusk of the family Assellotes, Leach, resembling the sow-bug. It pierces the hardest woods with cylindrical, perfectly smooth, winding holes, $\frac{1}{20}$th to $\frac{1}{15}$th of an inch in diameter, and about two inches deep.§ From ligneous matter having been found in its viscera, some have concluded that the limnoria feeds on the wood, but since other mollusks of the same genius, Pholas, bore and destroy stone-work, the perforation may serve only for the animal's dwelling. The limnoria seems to prefer tender woods, but the hardest do not escape. Green-heart oak is the only known wood which is not speedily destroyed.‖ At the harbor of Lowestoft, England, square fourteen inch piles were, in three years, eaten down to four inches square.¶

While all agree that no preparation, if we except dead oil, has repelled the limnoria, an eminent English engineer has cited three cases in which that agent afforded no protection.**

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[*] *Civ. Eng. Jour.*, vol. xii., p. 382. Also *Dict. Univer. d'His. Natur.*, tome xii.

[†] *British and Foreign Medical Review.*

[‡] *Civ. Eng. Jour.*, vol. xii., p. 191.

[§] *Dict. Univer. d'His. Natur.*

[‖] *Civ. Eng. Jour.*, vol. xxv., p. 206.

[¶] Ibid., vol. xvi., p. 76.

[**] Ibid., vol. xxv. p. 206.

We do not find that timber impregnated with water-glass ha ed against this subtle foe. The experiment is certainly worthy

A mechanical protection is found in thickly studding the the timber with broad-headed iron nails. This method h successful.[†] Oxydation rapidly fills the interstices between and the outside of the timber becomes coated with an imp crust, so that the presence of the nails is hardly necessary.

In conclusion, we cannot but express surprise that so little in this country concerning preservative processes. Their em seems to excite very little interest, and the very few works w are being tested attract hardly any attention. Those railro have suspended their use assign no reasons, and those upon timber is injected publish no reports concerning the adva their particular methods. Even the National Works, upon whic process was formerly employed, have laid it aside, and no lumber to dampness and alternations of wetness and dryness any preparation beyond seasoning. When sleepers cost fifty creosoting thirty cents each, it is cheaper to hire money at cent., compound interest, than to lay new sleepers at the en years. Allowing any ordinary price for the removal of th laying down the new ties, the advantage of using Bethell' seems evident. If some cheaper method will produce the sa the folly of neglecting *all* means, seeking to increase the dur the material is still more palpable.

Complete and reliable reports upon the preservation of th species of woods experimented upon in this country are greatl and we hope they may shortly appear.

[*] *Civ. Eng. Jour.*, vol. xii., p. 382.

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INVESTIGATIONS

ON

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RON AND STEEL RAILS,

MADE IN EUROPE IN THE YEAR 1873,

BY

T. EGLESTON, PH. D.,

SCHOOL OF MINES, NEW YORK CITY.

FROM VOL. III TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

PHILADELPHIA:
SHERMAN & CO., PRINTERS.
1876.

INVESTIGATIONS
ON
ON AND STEEL RAILS
MADE IN EUROPE IN THE YEAR 1873.

Y PROF. T. EGLESTON, SCHOOL OF MINES, NEW YORK CITY.

RING the year 1873, my attention was called to the frequent nts, resulting from the breaking of rails, on the different rail- in this country, and I was requested to investigate the subject. lan of investigation I proposed was to ascertain, in as many as possible, the exact history of broken rails, both in this ry and in Europe; to collect information in Europe relating to sts which rails used there were required to undergo, and to ex- ent upon the pieces of rails broken on the road, with a view to ain whether their fracture was due to their chemical constitu- bad manufacture, to a reduction in strength owing to tempera- or to physical changes in the constitution of the rail.

e investigation was commenced by the collection of statistics, r this purpose I spent several months in Europe, collecting nation on the subject of broken rails, as well as the life of iron eel rails generally, and inquiring into the systems of purchasing f testing them employed by the railroads there, intending, on turn, to make a series of analyses of rails broken, both in this ry and in Europe; to ascertain, if possible, how far great cold n influence on the fracture; to examine whether the rail broken, on the road or afterwards, underwent, at or about the fracture, hysical change, and to make a series of experiments on the gth of rails manufactured in the United States or sold in the ican market.

fortunately, the panic of 1873 came on, just before my return Europe, and prevented the carrying out of the larger part of lan proposed; as, however, I had collected in the meantime, a number of statistics of different kinds from all parts of Europe, ad made a number of interesting experiments and investiga- I have thought it would be worth while to communicate some iole or any part of the material which is not up to As the strength of the rail is stipulated in the con- ain number of experiments are made in the presence of ieer of the manufacturer furnishing the rails, but under the on of the engineer of the railroad company, sent to the works that purpose. None of the verifications, however, have the effect in any way diminishing the responsibility of the guarantee of the e of the rail for the time fixed in the contract. No manufacturer allowed to underlet any part of his contract to another manufac- rer without the written consent of the company. The acceptance the works by the company does not guarantee the whole payment til the article contracted for, whether it is a car, a rail, a water- ik, steam-engine, or any other material about the railroad, has rn well and without repairs during a certain specified time.

Most of the rails manufactured are of the ordinary American ttern, though some companies still use the double-headed rail. on rails are not so generally used as formerly. On all the principal ads their place is being rapidly replaced by steel. Steel-headed ls are used by some of the companies, but there is no certainty at the weld of the iron to the steel will always be perfectly made. e general experience is that there is a tendency for the two ma- ials to separate. There have been a great many ingenious plans posed, to make the iron clamp the steel, or the steel clamp the n, but in view of the experiments made at the Northern Railroad France, it does not seem worth while to lay any but steel rails, re especially as the old steel rail has a value which no combina- n of iron and steel could have.

It does not necessarily follow, that what is done in Europe, is ter than what is done in this country. On the contrary, ropean railway companies have a great deal to learn from the ctice of this country, as is shown by the repeated reports made engineers of different countries, sent here for that purpose by ir governments; but in the manufacture of rails and the study of ir wear and tear, we have something to learn from them. I have en some pains to compare the contracts for the purchase of rails de by different companies, and give below an abstract of the con- cts made for the purchase of both iron and steel rails, including stipulations of all the roads of France whose contracts I have n able to procure. There is, necessarily, a great deal of same- s in these contracts, and as no one of the roads imposes all of the ditions which I give below, I have given the contracts somewhat in detail, at the risk of being tedious, since I do not know that they have heretofore been published in English. They are, certainly, not generally within the reach of our members.

CONTRACTS FOR IRON RAILS.

All of the roads furnish either a drawing or a steel pattern of the form of the rails, and the manufacturer is not allowed to make the rails until the company is assured that the rolls agree perfectly with the shape furnished. The toleration allowed in the transverse section is only ½ mm. more or less. This is done in order to take into consideration the difference which may arise from the wearing of the rolls, and accidental differences in the distance between them. They require a specimen, showing the quality of the iron to be used in the rails, to be sent to the office in Paris. The iron rails used by the Lyons and Orleans Railroad, are several types of the American and of the double-headed rail. For the double-headed rails the length is 5 m. for nine-tenths of the order; the last tenth may be composed altogether or in part of rails 4.96 m. To facilitate the manufacture, one-thirtieth part of the rails may be admitted 3.75 m. For the American rail, on the Lyons road, the length is 6 m. for nine-tenths, and 5.96 m. for the last tenth; one-thirtieth of the order may be in lengths of 5 m. and 3.75 m. The Northern Railroad contracts for rails of the American pattern of 37 kils. The normal lengths of this rail are 6 and 7 m. For a part of the contract which may not exceed one-tenth, and which is fixed by the chief engineer, the rails may be 6.96 m. to 5.96 m. long. One rail in twenty may be delivered of a shorter length than these, and may be either 4 or 5 m. It is always understood by all the roads that the short rails are to be manufactured from the long ones, which have to be cut on account of defects at their extremities. All the roads stipulate that they may order a certain number of rails of exceptional lengths, providing that the greatest length shall not exceed 10 m.

The Lyons road agrees to pay for all rails exceeding 6 m. in length 5 per cent. above the ordinary price. The Northern Railroad agrees to pay only 4 per cent. A toleration of two millimetres, greater or less, is accorded by the Lyons and Orleans Railroad in the length of the rail, provided that on the whole order it shall not exceed one per cent. The toleration fixed by the Northern road is never more than 1½ millimetres.

All rails which have been manufactured in the trials of the rolls, and all others manufactured after the rails have been accepted, but which are not in accordance with the model furnished, are rejected. The companies are always at liberty to change the shape of the rails, providing always that the special expenses necessary for these changes shall be allowed to the manufacturer.

The weight of the rails is determined by the model, and is ascertained by trial of the first rails delivered. In the reception of the rails, a toleration of 2 per cent. above or below is allowed, providing that the weight of the whole contract does not vary more than one per cent. Within this limit of toleration, the rails are paid for at their actual weight. Above it, the iron is not paid for, and any rails outside of the limits, either weighing too little or too much, may be rejected entirely if the company think best.

The blast-furnaces which produce the cast iron used are required not to use any ore which gives a brittle iron. If the rail is allowed to be made of different qualities of iron, the head *must* be fine-grained, but in general, the manufacture must be so conducted as to produce only fine-grained iron. It must be weldable, as hard and compact as the specimen which is furnished to the manufacturer, and not cold-short; in short, of a quality to resist the action of the wheels of the train without breaking, crushing, or becoming unwelded. The Northern Railroad classifies the iron to be used into three distinct classes, namely: first, granular iron; second, iron composed partly of grains and partly of fibres, and third, fibrous iron. In the packages for making refined iron, only first-class granular iron must be used. The Lyons Railroad prescribes that the foot of the American rail shall be made of fibrous iron. It requires that the piles shall be composed of two-third puddled iron and one-third merchant iron; that the width of the package shall be 20 centimetres at least, and its height 22 centimetres, and that its weight shall be 40 kilogrammes heavier, at the least, than that of the rail. All the bars used in making up the different layers must be of rectangular section. Each layer of puddled iron may be made up in width of two or three pieces at the most. The layers of refined iron which form the upper part of the package must all be of a single piece, and must represent one-fifth of the total weight of the package, in order to have in the section of the finished rail, on the surface exposed to the wheels, a thickness of at least one centimetre. The layers which are next to them should be entirely composed of the best puddled iron. All the pieces composing the package must be of a single length and straight. For the puddled iron, however, a few bars are allowed of two pieces, at the most, the smallest piece of which must be at least 30 centimetres in length. They, however must be adjusted end to end, with care, in such a way as to leave the least possible space in the interior of the package. No joint in the package should be directly above another joint, and for this reason the bars of puddled iron should not be of the same width. Fibrous iron may be used only in the last third of the package. Between it and the two first layers, granular iron only must be used. The Orleans Railroad allows the rail to be made entirely of puddled bar, or with such a proportion of old rails as the manufacturers think best. The packages, of which the covering for the head is made, must be made exclusively of rectangular bars placed together on the flat side, in regular layers, with cross joints, and each bar should be 54 mm. in width at the least. The packages for the head of the rail should be rolled flat, and not on the edges, so that the width of the covering will be parallel to the direction of the layers. The cover must be made of puddled iron of the best quality. It must be of a single piece, and represent one-third of the total weight of the package. The Lyons Railroad requires that the puddled iron used, either in the body of the packages for rails, or in the manufacture of the merchant iron for covers, should be of good quality, carefully worked, and the edges of the bars should be smooth. When they are shorter than the package, they must be placed together carefully, end to end, in such a way as to leave the least possible space between them. In the works where the rails are rolled in a single heat, the packages must be turned in the furnace, end for end, when the heat is three-quarters finished. In the works where there are two heats, it must be turned at the commencement of the second heat. All the companies reserve the right to prescribe in what direction the packages shall be rolled, and all require that the name of the manufacturer must be engraved in the last curve of the rolls, so as to be distinctly seen in each rail. The dimensions, form, and composition of the packages, as well as the drawings of the successive curves in the rolls, must be submitted to the company, without, however, this diminishing in any respect the responsibility of the manufacturer.

All the roads require that the rails shall be as carefully manufactured as possible, and that all those badly welded, laminated, cracked, or broken in any way, must be rejected. They require that they must be perfectly flat, both on the foot and head, and if they are not so, they must be straightened on their four faces with the greatest care, or rejected. This straightening is invariably required to be done, as far as possible, hot, immediately after the rails leave the rolls. If they, afterwards, when cold, require to be straightened, it must never be done by percussion, but by gradual and slow pressure produced by means of a screw.

All the surfaces of the rails must be clean and uniform. All the roads require that the ends of the rails must be cut off at a sufficient distance to be sure that the rail end is perfectly sound. All projecting iron must be removed either with a file or a graver, and the ends of the rail must be square with its axis. They all require that the final length should be made by cutting one of the ends in a lathe, planing machine, or with a milling tool, in such a way that there shall be no tearing or any other alteration of the surface at the end, and that all excess of matter shall be removed with a file or graver, but on no account with a hammer. Reheating any part of the rail, either to cut off the ends, or for any other reason, is positively forbidden, except in case of temporary accidents to the machine used for cutting them, and then, if absolutely necessary, only during the time that is strictly necessary to repair it. Every kind of repair done to cracks or other inequalities in the rail, whether done cold or hot, is forbidden.

Each extremity of the rail is pierced with two round holes, to receive the bolts of the fish-plates, the dimensions and position of which are fixed by a drawing furnished by the engineer. The Lyons road provides that in some cases one of these holes may be half round. Two cuts of a rectangular form must be made at the extremity of the American rail to receive the wedges which prevent its motion forward, the position and size of which are also given. These holes and cuts may be made by any process which shall suit the engineer of the company, but in any case the edges of the holes and of the cuts must be filed smooth and not left rough. If the positions of the holes and cuts do not conform to the drawing, the rails may be rejected. The rails must be classified in series, according to the manufacture of different days.

The Northern and Orleans Railroad require the rails to undergo the following tests. Each one of the rails selected for trial is placed on supports 1.10 m. apart, and must sustain, in the middle between the two supports, a pressure of 12,000 kgs. for five minutes, without preserving any sensible set after the test. The same rail, in the same position, must support during five minutes, without breaking, a charge of 30,000 kgs. The Orleans Railroad requires 25,000 kgs.

At the Lyons Railroad, the rails are placed on supports 1 m. apart, and should support a pressure of 13,000 kgs. for five minutes, without showing any perceptible set, and then for another five minutes, without breaking, a charge of 27,500 kgs.

After these tests, all the companies require that the rail should be broken by an increase of the weight. The Northern and Orleans Railroad require, that each one of the two pieces of the rail broken should be placed between supports 1.10 m. apart,—the Lyons Railroad makes the distance 1 m.,—and should then support, without breaking, the shock of a weight of 200 kgs.,—the Orleans Railroad requires 300 kgs.,—falling in the middle between the supports from a height of 2 m. for the Orleans Railroad, and for the Lyons and Northern Railroad, from a height varying, according to the temperature,

From 0° C., and below, of	1.30 m.
From 0° C. to +20, of	1.50 "
From +20° C. and above, of	1.70 "

This variation is made as the rails are not considered as capable of resisting as great a strain in cold weather as in warm. All the roads require that for this test the two supports should rest upon a block of cast iron, weighing at least 10,000 kgs., placed upon masonry at least 2.30 m. in diameter and 1 m. thick. The Orleans Railroad allows the foundation to be of oak or masonry. If one of the rails tested does not resist, the tests are continued upon a greater number. If more than one-tenth of the rails do not resist, all the roads reserve the right to reject the entire series.

Provisional receptions are being made at the works, as the rails are manufactured, for the object of sorting, weighing, and marking them. Up to the time of their being sent to the company, the rails must be preserved in a dry place, and kept from oxidation as far as possible. Those accepted must be marked at their ends, and in case the name of the works, made by a cutting in the last curve of the rolls, should not have come out in rolling, it must be marked cold in such a way that it shall be visible. The rails which have been rejected must either be broken, or marked in such a way that the mark cannot be effaced.

All the roads provide that the tools for making the tests, as also all the labor of accepting and testing the rails, must be made at the expense of the manufacturer. The report of the tests and receptions are made every day. Every rail marked, and comprised within the report of acceptance made at the works, becomes, by the act of reception at the works, the property of the company.

All the roads require the manufacturers to allow the agents gineers of the companies to have free entry to the works during e time of manufacture, and to watch it day and night, if they wish ascertain whether the conditions of the contract are being carried t with respect to quality, resistance, and proper manufacture; but is understood that all observations or remarks which the agents of e company have to make, should be addressed to the director of e works and not to the workmen.

The manufacturer is made responsible for all delays which may ult from the rails delivered not being in accordance with the conct. The Orleans Railroad stipulates that, if there is any delay in e delivery of the rails, an indemnity of one per cent. per month on e price of the rails may be charged to the manufacturer. If after ving been notified that this delay is injuring the company, the nufacturer still delays to furnish the rails for a month longer, the npany is at liberty to rescind the contract.

The manufacturer takes all the risk and expense of loading, transrting, and discharging the rails up to a point agreed upon by the mpany for delivery, and he agrees to pile them there in regular es.

The Northern Railroad requires that the rails must stand a wear at least two years without any alteration whatever. The Lyons ilroad requires that they shall stand the passage of at least 15,000 ins. The Orleans Railway makes the life of the rail 2, 3 and 5 ars, depending upon the traffic over the section of road on which is placed, and stipulates that this guarantee does not apply, in any y, to provisional lines, nor to switches in the quarries, etc., but ly to the main line of the road. The manufacturer agrees to ake a stipulated reduction in the price of the rails according to e number which have not resisted during the prescribed time.

The Northern Railway requires that 10 per cent., at least, of the ils furnished are to be placed on the road in positions selected by e company, of which the manufacturer is to be notified. At the d of two years, the number of rails which have undergone any ind of deterioration, such as crushing, unwelding, exfoliation, or reaking, are counted, and allowance must be made for them by the anufacturer. It reserves the right to commence the testing of ils on the road-bed whenever it pleases, but agrees that the inemnity must be settled within two years, at the latest, after the reipt of the rails, whether the trial on the road is finished or not. he responsibility of the manufacturer does not cease until the rails ave been definitely accepted by the company.

All the roads provide that the reception of the rails by the company does not diminish the responsibility of the manufacturer to replace rails which break, either in transportation or within the times specified by the contract after they are laid. The Orleans Company requires that broken rails shall be replaced within a month after the manufacturer is notified that they are broken.

All the companies stipulate that no part of the contract can be sublet without the written sanction of the company.

The Lyons and Orleans Railroad agree that 85 per cent. of the value of the rails which have been received at the works shall be paid in the course of a month, after their reception, 10 per cent. within a month which follows the delivery of the rails at the place agreed upon by the company; the last 5 per cent. is paid by the Lyons Company on the final reception, and by the Orleans Company the year after the guarantee of the rails has been fulfilled. A certain sum is fixed by the Orleans Railroad, however, which the last five per cent. shall not exceed, and when this amount retained exceeds the amount stipulated, the second payment is raised to 15 instead of 10 per cent.

CONTRACT FOR STEEL RAILS.

The contract for delivery of steel rails generally requires, that the rail shall be of the American pattern, a steel or iron profile of which is furnished to the manufacturers. It requires that this profile shall be followed exactly, throughout the entire length of the rail, so that there will be no alteration of the section, when the rails are cut to length. All rails which do not fulfil this condition are rejected. A toleration of one per cent., however, at the greatest, is allowed. On the Lyons Railroad the rail weighs 35 kgs. They provide the foot of the rail shall be 100 mm. wide, its height 128 mm., and the stem of the rail 14 mm. thick. If the manufacturer makes a rail 130 mm. wide, whose foot has been damaged in the rolls, they will allow him to plane it down to 100 mm., providing that all the defects are in this way removed. The Northern and Orleans Railroad do not prescribe the dimensions, but furnish the pattern which the manufacturer is required to follow.

The normal length of the rail at the Northern Railroad is 8 m., but one-tenth of the amount of the contract may be delivered in rails cut to the length of 7.96 m. Besides this, another fraction, which varies from one-fifteenth to one-twentieth, may be delivered 7 m., 6 m., 5 m. long respectively, the quantities of each length being fixed by the company. At the Lyons Railroad the length of the rail is fixed at 6 m. for nine-tenths of the whole order; the other one-tenth may be composed in part of rails 5.96 m. in length. In order to facilitate the manufacture, one-thirtieth part may be accepted in rails of a shorter length than 5.96 m., but it is understood that these rails shall be made entirely of rails intended to be 5.96 m., or 6 m. in length, which were cut off on account of defects in their ends. The number of these short rails is determined by the contract. All the companies stipulate that the short rails shall be made from rails intended to have been longer, but whose ends have been cut on account of defects. All the companies reserve the right to order longer rails, for a certain price fixed upon beforehand.

The rails are generally cut to length hot, as they come from the rolls, by means of saws which cut both ends at a time. The definite length is afterwards given in a lathe, or milling machine, or by any other means which is not likely to injure the end of the rail, and which is acceptable to the company. The Lyons Railroad reserves the right of at any time modifying the shape of the rail, without the manufacturer being able to claim any indemnity, but the company binds itself to accept all the rails made previous to the modification, and conformable to the present contract. The normal weight of a metre of the rail is always established on the first delivery of 100 rails, whose sections are conformable to the model. In the reception at the works, a toleration of 2 per cent. more or less is allowed, provided that on the whole order the variation does not exceed 1 per cent. Over 1 per cent. the increase of weight is not paid for. A rail which is too heavy, may be entirely rejected if the company see fit.

The cast iron and other material, out of which the steel rail is to be made, must be made from ores sufficiently pure to be certain that the rail produced will be tenacious and hard. The cast steel manufactured may be made either in crucibles or in furnaces, or by the Bessemer process. Sometimes the contract specifies that they shall be of Bessemer steel. The operation must be conducted in such a way as to give first-class steel, fine-grained, homogeneous, hard, tenacious, and capable of being tempered throughout, when drawn out into bars of from 15 to 22 mm. square. In all cases the manufacturer is required to furnish samples to which the rails must conform. The manufacture of the rails is not allowed to commence until a type specimen of the steel has been submitted to the engineer of the company. The ingots for the manufacture of the rail are required to be of, at least, a single piece for each rail. The Northern Railroad, for the rail of 30 kgs., requires the section of the ingot to be at least 22 by 20 cm., if they are square, or if circular, a diameter of 23 cm. The Lyons Railroad requires for the rails of 35 kgs., the rectangular ingots to have their angles rounded, to be at least 25 cm. square, or if they have a circular section, a diameter of at least 28 cm., and stipulates that the weight of the ingot must exceed that of the rail to be manufactured by at least 35 kgs. The Orleans Company does not prescribe the size of the ingots. The section of these ingots may not be modified without the approbation of the engineer. After casting the ingots, the liquid metal must be covered over with a piece of sheet iron, and argillaceous sand must be thrown upon it and pressed down, so as to fill up the interior of the mould at the top. The ingots must be examined with care, and those which show blow-holes or impurities, or other defects, which the rolling will not cause to disappear, are rejected. Simple cavities, as well as thin edges of metal on the sides, whether caused by defects in the ingot moulds or not, must be cut off with the greatest care before the ingots go to the rolls, and over a sufficient space to make it impossible for the sides of the blow-hole or of the edges to turn over. Any ingots showing cracks or breaks, or otherwise defective, are to be rejected. The ingots must be heated only sufficiently for them to undergo the operation of rolling, and the rolling must be so conducted as to get the exact form of the rolls, and every effort must be made to prevent the rail from being bent as it comes out of the rolls. The Orleans Railroad requires, that in case the manufacturer carries on his works in two places, and that the ingots are made at a different place from that in which the rails are made, the ingots must be classified separately, and their place of manufacture indicated by marks, so that the agents of the company may be able, if necessary, to ascertain the history of their manufacture. One ingot out of every twenty castings is broken. If this ingot shows, in the part adjacent to the outside, blow-holes in any number which are more than 30 mm. in depth, the entire casting from which it came may be rejected.

The fracture of the rails must be fine-grained, nearly compact, entirely homogeneous, without brilliant white points resembling the fracture of cast iron. The hardness is regulated by the type specimen which is furnished by the company. Repairing the rails, either cold or hot, is positively forbidden. The surfaces of the rails are required to be smooth and uniform. All the rails which show racks, breaks, lamellated surfaces, etc., coming from blow-holes, racks, or flaws of any kind are rejected. Only such superficial cracks or imperfections are tolerated, as cannot in any way injure the strength of the rails.

All the roads require that the rails shall be straight through their entire length, and that they must, as far as it is possible, be straightened on all the four faces hot, as they come out from the rolls. This must be done on cast-iron plates, or any other suitable bed arranged for the purpose, and the rails must then be placed on a solid structure to cool. The final straightening, made when the rail is cold, must be made by a gradual pressure, without shock, and in performing the operation the foot of the rail must be arranged in such a way that there will be no danger of cracks being produced in it.

The ends cut off from the rails must be examined for texture, and if the quality is not sufficiently good, the rails are to be rejected. The length to be cut off from the ends of the rails, is 70 cm. for the extremity corresponding to the upper part of the ingot, and 30 cm. for that corresponding to the lower part. The hot rails, as they come from the rolls, are to have both ends cut with a saw. The final length is given cold in a lathe, planing or mortising machine. Heating the ends of the rails, in order to cut them, is positively forbidden. Whenever the rails are cut with a saw, as they come out rom the rolls, their ends must be carefully dressed. Whatever the nethod of dressing the ends may be, it must be conducted in such a vay as to make no alteration in the form of the end of the rail, and he method must always be approved by the company. The end urfaces of the ends of the rails must always be parallel and at right ngles to the axis of the rail. All superfluous metal must be cut off vith a graver or file, the use of the hammer for this purpose being ositively forbidden.

All the rails must have two square cuts at each end, and must also ave at each end two holes for the fish-bolts, which must be bored vith a drill in the stem of the rail, in accordance with plans and rawing which are given, and which prescribe not only the size and lace of the holes, but also the methods of boring them. These oles must never, for any reason, be punched. The edges of these oles must be perfectly clean, and all superfluous metal must be emoved with a file. The Orleans and Lyons Railroad allows a oleration of only ½ millimetre in the distance and size of these oles.

All the rails must have the name of the works, the year and month of the manufacture, and the kind of steel, whether cast, Bessemer, or Martin, marked on them in relief. All these marks must be engraved in the rolls, except that denoting the nature of the steel, which may be made with a point after the rails are finished.

All the rails are classified as soon as possible after they are made, so that they can be inspected and tested at the works, those made during one, two, three, or four days, or those from the same casting, being piled together. The engineer designated to receive the rails, takes from these piles a number of rails, and the corresponding rail ends, to be tested. The number is variable; it is not more than one per cent. on the Northern Railroad, and not more than one-half per cent. on the Lyons Railroad, while the Orleans Railroad reserves the right to test five per cent. of the rails, and their crop ends. The companies reserve the right of making tests on any other rails not comprised in these piles, provided the piece experimented upon is 0.70 m. in length, and without flaws. The tests are essentially the same in all the companies, but differ somewhat in detail, the differences corresponding, for the most part, to the weight of the rail. All the companies use the same type of testing machine, and a weight of 300 kgs., which is allowed to fall on the rail from different heights. At the Lyons Railroad, where the rail weighs 35 kgs., each one of the rails selected from the piles to be examined, is placed upon its foot between supports, 5 m. apart, and should be able to support, for five minutes, a charge of 2500 kgs., without receiving a permanent set of more than 1 mm. The same rail, placed between supports 1 m. apart, must support for five minutes, in the middle between the supports, a pressure of 20,000 kgs., without receiving a permanent set of more than ¼ mm. The same bar, in the same position, must support during five minutes, a charge of 35,000 kgs., which will then be increased until the rail breaks. At the Northern Railroad the tests of pressure are somewhat different. The rails are placed on supports 1.10 m. apart, and must support, in their middle, for five minutes, without receiving any permanent set, a pressure of—

20,000 for a rail weighing	37 kg.
18,500 " " "	35 "
17,000 " " "	30 "

Without having a permanent set of more than 0.25 mm. a pressure of—

35,000 for a rail weighing	37 kg.
33,000 " " "	35 "
30,000 " " "	30 "

The Orleans Railroad requires that the rail, placed on supports 1.10 m. apart, should support a weight of 16,000 kgs. for five minutes, without preserving any set, and without breaking; a weight of 35,000 kgs. also for five minutes. The pressure is then increased until the rail is broken.

At the Northern Railroad each one of the halves of the rail so broken, is then placed between supports 1.10 m. apart, which are fixed upon a block weighing, at least, 10,000 kgs., supported upon a foundation of masonry, which must be 1 m. in thickness, and 3.3 m. square at the base, and must bear, without breaking, a weight of 300 kgs. falling upon the middle of the bar, which, for a rail weighing

37 kgs., must fall from a height of	2.50 m.
35 " " " " "	2.40 "
30 " " " " "	2.25 "

The Lyons Railroad, for the rail weighing 35 kgs., requires a height of 1.70 m.

The following table shows the permanent set which will be admitted for rails of various weights by the Northern Railroad:

Height of fall in metres, ...	1	1.50	2	2.25	2.40	2.50
Permanent set in mm. for rails weighing 37 kgs.,	1	8	6	0	0	10
" " " " " 35 "	1	3.33	7	0	11	0
" " " " " 30 "	1	3.50	8	11	0	0

The Lyons Railroad requires the height of fall, 1.70 m.; permanent set for rails weighing 35 kgs., not over 12 mm. The Orleans Railroad requires the rail to resist a height of 2.10 m.

The elasticity of the bar will be shown by the way in which the weight rebounds when it strikes.

If one of the bars tested breaks below

2.50 m., for a rail weighing	37 kgs.
2.40 " " " "	35 "
2.25 " " " "	30 "

or should preserve at this height, a permanent set of more than 2 mm. beyond that indicated, the Northern Railroad requires the test to be continued on a greater number of rails, and if more than 1-10th of the rails tested do not resist, the entire pile from which they were taken is rejected.

The Orleans Railroad provides that all the five crop ends of the rails selected may be broken by the drop-hammer, in order to examine their texture, and that the rail corresponding to the rail end which has the worst fracture, shall be selected as the one to undergo the test of shock. If this rail resists, the rest of the series will be accepted, but if, on the contrary, it breaks, a second rail will be tried, and so on. If each one of the five rails breaks then the whole hundred will be thrown out. At the Lyons Railroad, if one rail does not stand the test, all the rails from the same casting may be rejected, unless the manufacturer desires to continue the testing upon two other bars which, if they resist, will cause others to be accepted. At each casting, one ingot heavier than the others is required to be made, in order to get a sound rail of 70 cm. greater length than the others. This 70 cm. is at once cut off from the rail, and must correspond to the upper end of the ingot.

The number of the casting, and the other marks made upon the ingot from which this end for testing was made, are reproduced upon the piece of rail. This piece of the rail is placed on two supports 50 cm. apart, and must support the shock of a weight of 300 kgs. falling on the middle from a height of 1.30 m. The two supports are made of cast iron, with round angles, and rest upon the same kind of a foundation as that upon which the rails are tested. When this end of the rail does not support the test, a rail of the corresponding casting is submitted to the test of shock and flexure, and if it does not resist, the whole casting may be rejected.

A piece of the head of the rail, at least 20 cm. in length, is then broken and heated to cherry-red and plunged into cold water, in order to get a hard temper. The surface of the piece should then be white, perfectly clean, and with difficulty touched with a file. If the steel is of good quality it should, during its immersion, produce considerable noise, with slight explosion, and crack in several places. It must be broken afterwards in the middle, in order to judge of the degree of temper and the transformation of its texture. A piece of the same rail, 3 cm. wide and 2 cm. thick, is then drawn out and submitted to the same test. The result should be the same, but the grain of the fracture should be much finer than that of the specimen of the rail tempered without being drawn down. The test of tempering is made upon one casting out of ten consecutive ones. From a piece of the same rail a graver, a turning tool, a mortising tool, and a planing tool should be made. These tools, tempered in the ordinary way, should without breaking or bending, cut the outside bed of a white iron casting. The Orleans Railroad requires that the rail should be forged from 20 to 30 mm. square, and be tempered so hard that they will break easily.

'he fracture of the broken rail should have a fine uniform grain, nd a much finer texture than before tempering. A piece of rail is ıen rolled out to 75 mm. in length, and 1 cm. thick, and made in ıe shape of a spring. The spring is laid upon supports and tested ith a weight placed upon its convex side, in the middle. The pring should be capable of being lengthened 4 mm. per metre, withut breaking. All the rails submitted to the test by shock should ndergo this trial.

A provisional acceptance of the rail is made by the agents of the ompany at the works, and, so far as possible, as they are manufacured. The object of this is to sort, weigh, and mark all the rails hich fulfil the stipulated conditions. All rails which, either in ransportation, before or after being laid upon the road-bed, are roken within a certain specified time, must be replaced. The entire xpense of the apparatus for making the tests, as well as the labor f receiving and testing the rails, is borne by the manufacturer. All he rails accepted are marked at their ends, and those which are rected are also marked in a way that will effectually prevent their ver being used on the road-bed. All of these marks must be easily en, and must be made in such a way that they cannot be effaced. 'he Northern Railroad requires a guarantee of the rails for six years om the date of their manufacture, whether they are employed on ıe direct line or upon switches. The Orleans Railroad especially rovides that the guarantee shall not extend to rails laid in ballast uarries, or put down for the purpose of building any part of a new ad.

Every rail that during this time is broken, or becomes deteriorated ı any other way than by ordinary wear, must be replaced by the ıanufacturer. This exchange of damaged rails for new ones is efcted at places indicated in the contract. At the Lyons Railroad, l rails which are broken or injured before 15,000 trains have passed ver them must be replaced. Whatever may be the cause of the acture, all the rails broken within a period of 3 years and 3 months fter they are delivered must be replaced, or, if the manufacturer oes not care to replace them, he may indemnify the company in ıoney. In order to ascertain what this is likely to be, 5 per cent. f the rails delivered may be placed by the company on its line, on urves, or wherever else it shall be judged most convenient, and the ıanufacturer is notified of these places. At the expiration of the elay necessary for the passage of 15,000 trains, all the rails which how a commencement of deterioration, like crushing, want of proper welding, exfoliation, fracture, etc., comprising those which have been already replaced, shall be noted.

The proportion which is fixed in this way, is applied to the entire order. The indemnity for every ton of rails, without taking into consideration rails which may still be used by being made shorter, is fixed by contract and is intended to represent the difference in value between a ton of the new rails and a ton of the rejected rails, both delivered in the depot nearest to the manufacturer; but the rejected rails, except the broken ones which are replaced, will remain the property of the company. The rails must be delivered on the cars at the railroad station nearest to the works of the manufacturer, or deposited in regular piles, which can be easily counted, at some other place, if so indicated by the contract. Transportation from the works to the place of delivery is in all cases to be made at the risk and expense of the manufacturer.

The payments are made at Paris. The Lyons Railroad pay 95 per cent. of the value of the rails at the end of a month after their delivery, the other 5 per cent. after their final reception. Both the manufacturers and the railway companies are exceedingly particular in their instructions with regard to the treatment of rails in transporting them on the cars, and particularly in discharging them from the cars; throwing the rails or allowing them to fall from any height being most positively forbidden.

The care of rails is, in some instances, even carried to excess. Some companies who distribute their rails at certain points along the road, in order to provide for possible accidents, house beside the track all the rails so distributed, in order to prevent oxidation. This housing is, certainly, very desirable in the winter-time, when the rails are likely to become frozen together, but it does not seem necessary for the cause assigned, for the danger from oxidation, except in contact with acid waters, is exceedingly trifling. The rails broken upon the road are usually brought to the workshops of the main office of the road, and the pieces tested. It is very rare that the pieces so tested do not resist a force superior to that required by the contract.

As an example of the way in which this testing is done, and the care which is taken to see that all the rails are up to the required standard, I give below two examples of the details of testing broken ils. These experiments were made at my request, and in my presice, under the direction of Mr. Contamin, who had charge of that partment, at the works of the Chemin de Fer du Nord, at Ermont, ar Paris.

Both the rails tested were of steel, and had been broken on the ad while I was in Paris, and were sent to the works at my request r the purpose. The first experiment was made upon a rail weigh-g 35 kg. per metre, manufactured at Creusot. This rail had been wn one year. It was found broken 2.15 m. from one end. The acture was uniform, and without blow-holes or dark spots. The wer part of the fracture on the foot of the rail was quite smooth, hich seems to show that there had been more or less vibration at at point, and that the fracture had commenced there. Both pieces the rail were tested. One of them was 5.75 m., and the other 15 m., so that the rail was originally 7.90 m. in height.

TEST OF THE PIECE 5.75 M. IN LENGTH, BROKEN ON THE ROAD.

The piece of the rail was placed upon supports 1.10 m. apart, id subjected to the fall of a weight of 300 kg. under the exact contions of the contract, the results of which are given in the table low:

eight of fall,	1 m.	1.50 m.	2 m.	2.25 m.	2.50 m.	3 m.	3.25 m.
rmanent set,	1 mm.	7 mm.	16 mm.	24 mm.	33 mm.	44 mm.	broke.

The rail, when struck by the weight, gave out a silvery sound, id was so elastic that when struck from a height of 1.50 m., the eight rebounded several times at each stroke, and the rail turned ttom up in the supports, so that the head was down. The rail as always replaced in its proper position when it turned over. At e height of 3 m., the rebounding weight falling upon the rail hich had turned when the weight first struck it, so that the foot of e rail was uppermost, but the rail was not horizontal, broke off a ece of the foot, for which reason the rail broke at that point at the xt fall, which was 3.25 m. This piece of the rail was now broken to two pieces, which were 2.45 m. and 3.30 m. in length. Both of ese pieces were tested.

Tests upon the piece 2.45 *m. in length.*

Height of fall, .	. 1 m.	1.50 m.	2 m.	2.25 m.
Permanent set,	. 4 mm.	10 mm.	22 mm.	broke.

It will be noticed that the permanent set here was much greater than in the case of the first piece, but the rail did not break until it arrived at the limit required by the contract. The fracture was light-gray, but dotted with small brilliant points which did not appear in first test.

Test on the piece 3.30 *m. in length.*

Height of fall,	1 m.	1.50 m.	2 m.	2.25 m.	2.50 m.	3 m.	3.25 m.
Permanent set,	3 mm.	5 mm.	10 mm.	16 mm.	20 mm.	28 mm.	broke.

It will be noticed that the set in this case is very much less than in the former tests. The piece was so elastic, that the weight rebounded from it, and from 2 m. onwards the rail turned over, after every stroke of the weight. The fracture was entirely regular, and similar to the fracture of the first piece.

TEST OF THE PIECE 2.15 M. IN LENGTH, BROKEN ON THE ROAD.

Height of fall,	1 m.	1.50 m.	2 m.	2.25 m.	2.50 m.	3 m.	3.25 m.
Permanent set,	6 mm.	16 mm.	36 mm.	54 mm.	74 mm.	98 mm.	120 mm.

The sound produced by the fall of the weight was not so sonorous as in the former cases. The rail did not turn over in its support, and the weight did not rebound until after the second shock, and then only once after each shock instead of several times as in former cases. When the flexure of the rail had reached 120 mm., it was so much bent, that it touched the bottom between the two supports. It was then turned over and straightened, by allowing the weight to fall upon the foot. After three successive shocks from a height of 3 m., the rail became perfectly straight, but at the last shock a piece of the foot 15 cm. in length was broken off. The rail was then placed with the head up, but the first blow from a height of 3 m. broke it. The fracture was clear gray without brilliant points, but appearing as if the crystals had been elongated. This test shows a very extraordinary resistance to rupture, within 85 cm. of the point where the rail broke upon the road.

This rail was thus broken five times, once upon the road and four times in these experiments. Although the resistance to rupture in the four experiments is very unequal, and the different parts of the rail seem not only to have a different resistance, but a different elasticity, they are all within the limits prescribed by the contract; and, therefore, in a commercial sense, the original fracture cannot be said to be owing to the inferior quality of the rail.

The fracture on the road was probably caused by an imperfection
ıich was undoubtedly commenced in a small crack, probably pro-
ced either in straightening the rail, or in discharging it from the
:s. The irregularity of the resistance was so great that I had
ces cut off near the breaking points of each one of the pieces of
ls, preserving the fractured surface on one side. The other side I
d polished so that it might be etched by acids. In this way I
ped to discover any irregularity of texture.

The other rail broken was manufactured at Terrenoire and had
en in use 16.5 months. It was laid on the 16th of December,
72, and taken up broken on the 15th of April, 1873. The frac-
re commenced in the body near the head, and just above the fish-
ıte holes, and extended from thence a short distance, parallel to
e head of the rail, and then curved irregularly until it reached the
)t, 40 cm. from the end of the rail. It was placed on supports as
ual and broken.

TEST OF THE RAIL.

Height of fall, . .	1 m.	1.50 m.	2 m.	2 25 m.	2.50 m.
Permanent set, . .	2.8 mm.	6.7 mm.	12.1 mm.	17 mm.	broke.

The half towards the end which had been broken on the road
as now placed between supports and broken.

Height of fall, . . .	1 m.	1.50 m.	2 m.	2.25 m.	2.50 m.
Permanent set, . .	2.9 mm.	6.7 m.	12.9 mm.	19.6 mm.	broke.

It will be noticed that the sets in this rail, with the exception of
e last one, were almost absolutely identical. The rail appeared to
uniform throughout. The fracture showed a clear grain, some-
ıat larger than the rail from Creusot, with elongated crystals.
)th pieces of the rail showed a resistance greater than that required
the contract, but it is still, however, in general, less than that
ıich is shown by most rails which are broken, and less than that of
e rails ordinarily furnished from Terrenoire.

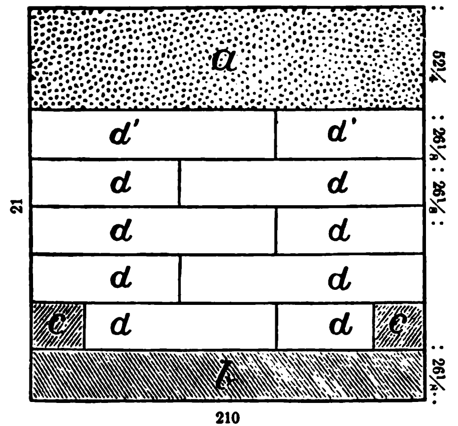
It must be seen, as a result of these experiments, that so far as we
e able to ascertain without chemical analysis, the probable cause
the fracture was in these instances improper handling of the rails.
certainly was not due to any defect in fulfilling the conditions of
e contract.

The following information, with regard to the method of piling rails in Germany, was collected at my request by W. A. Smith, E. M., at that time attached to the United States Legation at Berlin:

KÖNIGSHÜTTE, IN SILESIA.

FIG. 1.

Dimensions in millimetres.



Scale of ¼.

a. Fine-grain tough head-plate, rolled out of a package of puddle-bars.
b. Foot-plate, rolled out of good tough puddle-bars.
c. Inserted bars, rolled out of good tough puddle-bars.
d′ d′. Soft fine-grain puddle-bars.
d d. Ordinary puddle-bars.

In the finished rail: the head is three times reheated iron, the web is once reheated iron, the foot is twice reheated iron.

These works guarantee the rails for three years on levels over which not more than 16,000 axles pass daily.

The package is heated, hammered under a 4.5-ton hammer, again heated, and rolled out to the finished rail. These rails are guaranteed for five years, provided not more than 16,000 axles daily pass over them. Rails with a fine-grained iron head are guaranteed for four years under the same conditions.

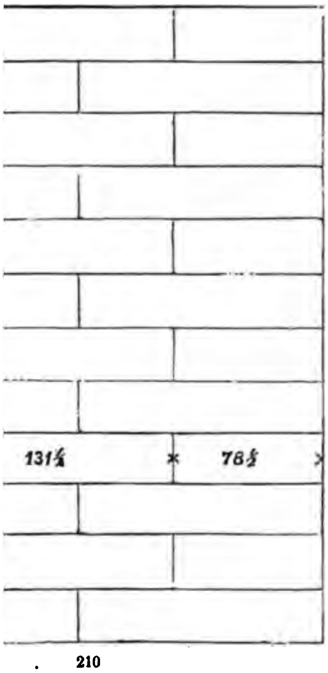
To form the head-plate *a* in Fig. 3, the package Fig. 2 is used. This is made of the best sorted puddle-bars, the side-plates—shaded in Fig. 3—being of once reheated iron rolled into the above form. In the head-plate, the longer edges of the original puddle-bars are placed vertically. The package Fig. 2 is heated, hammered under a 6-ton steam-hammer, and rolled out to *a*, Fig. 3. In Fig. 3, the plates *b b* are of once reheated good iron. This package, Fig. 3, is heated, hammered under a 6-ton steam-hammer, again heated, and d out to the finished rail. These rails are guaranteed for three in Germany only.

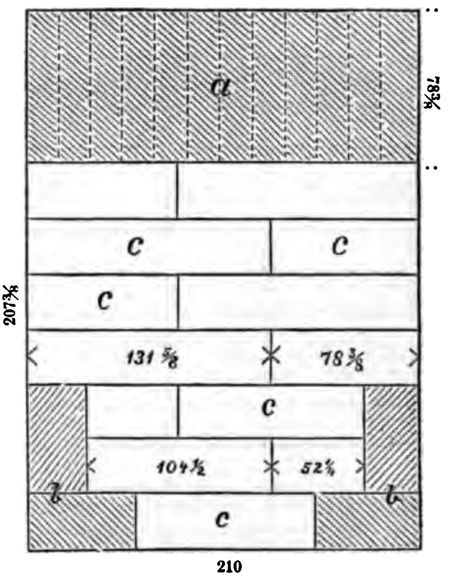
case the head is of steel, the package is made in the same way.

GUTEHOFFNUNGSHÜTTE AT STERKRADE ON THE RHINE.

FIG. 2. FIG. 3.

Dimensions in millimetres.





Scale of ¼.

. 2. Package of puddled steel bars which is rolled out to a bar of 0.210 m. 78⅝ to form the head plate *a* in Fig. 3. In the package, Fig. 3, and in the ed rail, the longer sides of the sections of puddle-bars would occupy a al position.

. 3. *a* Steel head-plate, rolled out of puddled steel bars.
b. Twice reheated tough iron.
c. Puddle-bars.

head-plate is rolled out of puddled steel bars; and, to secure a weld, the bars *c c*, are of fine-grain puddled iron. The rails uaranteed for five years in Germany only.

e shaded loupe-bars are of puddled steel, the others of tough For the better formation of the foot of the rail, the bars *b b*, f reheated tough iron. The package is twice heated and hamd under a 6-ton steam-hammer, is again heated and rolled out to the finished rail. After the second hammering, the package has a cross-section of 0.183 × 0.183 m. These rails are guaranteed for five years, provided they are not used about stations or on grades of 1.6 or above.

To form the head-plate *a* in Fig. 5, the package Fig. 4 is used. This is made of the best sorted puddle-bars, the side-plates,—shaded in Fig. 4,—being of once reheated iron rolled into the above form.

PHÖNIX EISENHÜTTEN-GESELLSCHAFT NEAR RUHRORT ON THE RHINE.

Dimensions in millimetres.

FIG. 4.

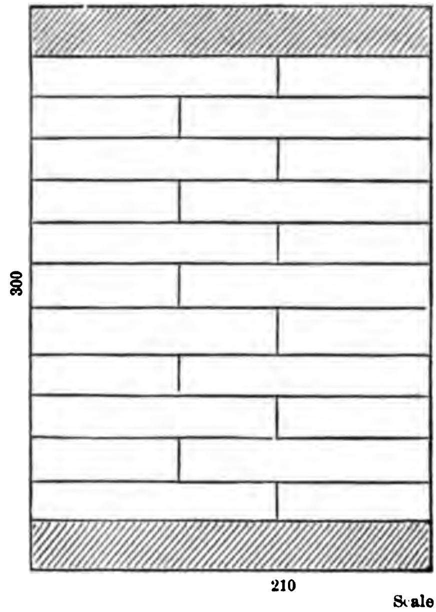
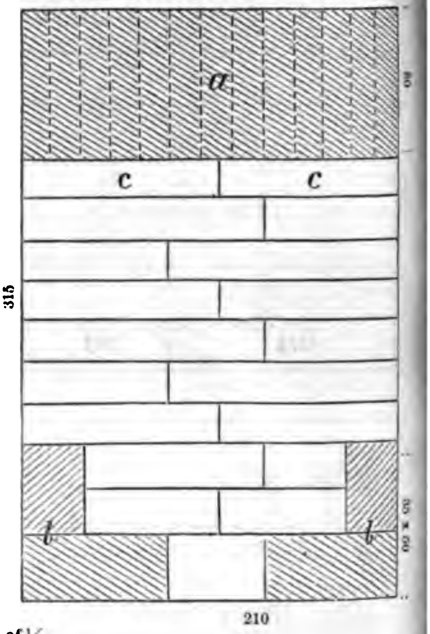


FIG. 5.



Scale of ¼.

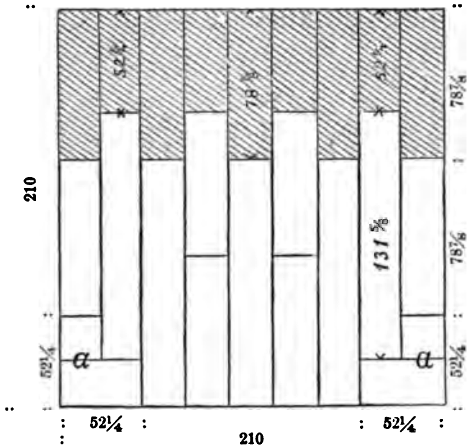
In the head-plate the longer edges of the orginal puddle-bars are placed vertically. The package Fig. 4 is heated, hammered under a 6-ton steam-hammer, and rolled out to *a*, Fig. 5. In Fig. 5, the plates *b b* are of once reheated good iron. This package, Fig. 5, is heated, hammered under a 6-ton steam-hammer, again heated, and rolled out to the finished rail. These rails are guaranteed for three years in Germany only.

In case the head is of steel, the package is made in the same way. The head-plate is rolled out of puddled steel bars; and to secure a good weld, the bars *c c* are of fine-grain puddled iron. These rails are guaranteed for five years in Germany only.

HOERDER BERGWERKS- UND HÜTTEN VEREIN, WESTPHALIA.

FIG. 6.

Dimensions in millimetres.



Scale of ¼.

The shaded loupe-bars are of puddled steel; the others of tough iron. For the better formation of the foot of the rail, the bars *a a* are of reheated tough iron. The package is twice heated and hammered under a 6-ton steam-hammer, is again heated and rolled out to the finished rail.

After the second hammering the package has a cross-section of 0.183 m. × 0.183 m. These rails are guaranteed for five years, provided they are not used about stations or on grades of 1.6 or above.

As it is important to ascertain the cause of fracture, in order to avoid it, I made an effort to get from all the roads a complete history of rails broken, as far as it was possible, and also to collect the records of the mean temperature of the month and year, and other details as to whether the rail was broken on the inside or outside of a curve of a given radius, or by a train going up or down a grade. Such a history was compiled for me by the Paris and Lyons Railroad, for three of its auxiliary lines, month for month, for the years 1869, 1870, 1871, and 1872, and merits a most careful and attentive study. The first and third of these roads used the iron double-headed rails, exclusively, up to the year 1872, when the Geneva line commenced by putting down 15½ kilometres of steel rails. The Tarascon line has used them since 1869, in small quantities at first, but gradually increasing them until, in 1872, there were twenty-one kilometres of steel rails on the line of the road. The St. Germain line had not used steel rails up to 1872.

Statistics of Rails broken per month on three of the Auxiliary Lines of the Lyons Railroad.

LINE FROM AMBERIEU TO GENEVA.

DATES.	DESCENTS.				ASCENTS.			Straight line.	LINE WITH A RADIUS OF CURVATURE.			Form of rail.	RAILS BROKEN.		Total.	Time that the rails were placed on the road.
	Above 0.008.	From 0.008 to 0.005.	From 0.005 to 0.002.	From 0.002 to ascents 0.002.	From 0.002 to 0.005.	From 0.005 to 0.008.	Above 0.008.		Above 500.	From 500 to 301.	From 300 and below.		After being turned over.	Before being turned over.		
1869.																
January	....	1	....	....	....	....	....	..	1	......	......	D. C.	......	1	1	1858.46
February	....	....	....	1	....	....	....	..	1	......	......	"	1	......	1	
March	....	1	1	....	1	....	....	1	1	1	......	"	1	2	3	
July	1	....	....	....	....	....	....	1	......	......	......	"	1	......	1	
August	....	....	....	1	....	....	....	..	......	1	......	"	1	......	1	
Septemb'r	....	....	....	....	1	....	....	..	1	......	......	"	1	......	1	
Novemb'r	....	....	....	1	....	....	....	..	......	1	......	"	......	1	1	
December	....	....	1	....	1	....	....	...	2	......	......	"	1	1	2	
Total, 1869	1	2	2	3	3	0	0	2	6	3	0		6	5	11	
1870.																
January	1	1	....	2	....	....	....	1	3	......	......	D. C.	4	......	4	1858.97
February	....	....	....	....	1	2	....	2	1	......	......	"	3	......	3	
March	....	1	1	....	....	....	....	..	2	......	......	"	1	1	2	
April	....	....	....	....	....	1	....	1	......	......	......	"	......	1	1	
June	....	....	....	1	....	....	....	..	1	......	......	"	......	1	1	
August	1	....	....	....	....	....	....	1	......	......	......	V.	......	1	1	
Septemb'r	....	....	....	....	....	....	1	1	......	......	......	D. C.	1	......	1	
October	1	....	....	....	....	....	....	1	......	......	......	"	......	1	1	
Novemb'r	....	....	....	3	1	....	1	..	4	1	......	"	3	2	5	
December	2	....	2	1	4	....	....	4	1	4	......	"	3	6	9	
Total, 1870	5	2	3	7	6	3	2	11	12	5	0		15	13	28	
1871.																
January	3	7	10	7	5	2	4	17	15	6	......	D. C.	23	15	38	1860.34
February	2	2	1	5	....	1	1	4	7	1	......	"	8	4	12	
March	2	2	2	1	1	2	....	3	6	1	......	"	8	2	10	
April	1	1	1	....	....	1	....	1	2	......	......	"	3	......	3	
May	1	1	....	....	....	....	....	..	1	1	......	"	1	1	2	
July	1	....	....	....	....	....	....	1	......	......	......	"	......	1	1	
August	1	2	....	....	....	....	1	2	2	......	......	"	3	1	4	
Septemb'r	....	....	....	....	....	1	....	..	1	......	......	"	......	1	1	
October	....	....	....	....	1	....	....	1	......	......	......	"	1	......	1	
Novemb'r	....	1	....	3	....	2	....	3	3	......	......	"	5	1	6	
December	7	....	....	4	....	....	....	6	2	3	......	"	8	3	11	
Total, 1871	18	16	14	20	7	8	6	38	39	12	0		60	29	89	
1872.																
January	3	....	....	1	3	2	2	3	4	4	......	D. C.	9	2	11	1862.01
February	1	....	....	1	3	1	....	2	4	......	......	"	4	2	6	
March	....	....	....	....	1	1	3	4	1	......	......	"	2	3	5	
April	1	1	....	1	....	....	1	1	1	2	......	"	2	2	4	
June	....	....	....	1	....	1	....	1	1	......	......	"	1	1	2	
July	1	....	....	1	....	....	1	1	1	1	......	"	1	2	3	
August	....	1	....	1	....	....	....	..	2	......	......	"	2	......	2	
Septemb'r	1	....	....	3	....	....	....	4	......	......	......	"	2	2	4	
October	....	....	....	1	....	....	1	..	1	1	......	"	2	......	2	
Novemb'r	3	....	....	1	....	....	1	1	2	2	......	"	3	2	5	
December	7	....	....	1	....	...	2	3	4	3	......	"	9	1	10	
Total, 1872	17	2	0	12	7	5	11	20	21	13	0		37	17	54	

LINE FROM TARASCON TO CETTE.

1869.																
February	....	....	....	1	....	....	....	1	......	......	......	D. C.	1	......	1	1859.00
Novemb'r	....	....	....	2	....	....	....	2	......	......	......	"	2	......	2	
December	....	....	....	1	....	....	....	..	1	......	......	"	1	......	1	
Total, 1869	0	0	0	4	0	0	0	3	1	0	0		4	0	4	

NOTE.—D. C. signifies double-headed rail. V. signifies American rail.

Statistics of Rails broken per month on three of the Auxiliary Lines of the Lyons Railroad.

LINE FROM TARASCON TO CETTE.—*Continued.*

DATES.	DESCENTS.				ASCENTS.			Straight line.	LINE WITH A RADIUS OF CURVATURE.			Form of rail.	RAILS BROKEN.		Total.	Time that the rails were placed on the road.
	Above 0.008.	From 0.008 to 0.005.	From 0.005 to 0.002.	From 0.002 to ascents 0.002.	From 0.002 to 0.005.	From 0.005 to 0.008.	Above 0.008.		Above 500.	From 500 to 301.	From 300 and below.		After being turned over.	Before being turned over.		
1870.																
January	....	....	....	1	....	....	....	..	1	......	......	D. C.	1	......	1	1860.00
February	....	....	....	1	....	....	....	1	......	......	......	"	......	1	1	
March	....	....	....	1	....	....	....	1	......	......	......	"	1	......	1	
July	....	....	....	1	....	....	....	1	......	......	......	"	1	......	1	
December	....	....	....	2	....	....	....	1	1	......	......	"	1	1	2	
Total, 1870	0	0	0	6	0	0	0	4	2	0	0		4	2	6	
1871.																
January	....	....	....	2	....	....	....	1	1	......	......	D. C.	2	......	2	1861.00
February	....	....	....	1	....	....	....	1	......	......	......	V.	......	1	1	
June	....	....	....	1	....	....	....	1	......	......	......	"	......	1	1	
October	....	....	....	....	1	....	....	..	1	......	......	"	......	1	1	
Novemb'r	....	....	....	1	....	....	....	1	......	......	......	D. C.	1	......	1	
Total, 1871	0	0	0	5	1	0	0	4	2	0	0		3	3	6	
1872.																
January	....	....	....	1	....	....	....	1	......	......	......	D. C.	1	......	1	1862.00
March	....	....	....	2	....	....	....	2	......	......	......	D.C.&V.	1	1	2	
December	....	....	....	1	....	....	....	..	1	......	......	V.	......	1	1	
Total, 1872	0	0	0	4	0	0	0	3	1	0	0		2	2	4	

LINE FROM ST. GERMAIN-DES-FOSSES TO BRIOUDE.

DATES.	DESCENTS.				ASCENTS.			Straight line.	LINE WITH A RADIUS OF CURVATURE.			Form of rail.	RAILS BROKEN.		Total.	Time that the rails were placed on the road.
	Above 0.008.	From 0.008 to 0.005.	From 0.005 to 0.002.	From 0.002 to ascents 0.002.	From 0.002 to 0.005.	From 0.005 to 0.008.	Above 0.008.		Above 500.	From 500 to 301.	From 300 and below.		After being turned over.	Before being turned over.		
1869.																
January	....	....	....	1	....	....	....	..	1	......	......	D. C.	1	......	1	1859.01
February	....	....	1	....	....	....	....	1	......	......	......	"	1	......	1	
October	....	....	....	1	....	....	....	1	......	......	......	"	1	......	1	
Novemb'r	....	1	....	....	....	....	....	..	......	1	......	"	......	1	1	
December	....	....	....	....	....	1	....	..	1	......	......	"	......	1	1	
Total, 1869	0	1	1	2	0	1	0	2	2	1	0		3	2	5	
1870																
February	....	....	1	....	....	....	....	1	......	......	......	D. C.	1	......	1	1859.91
April	....	....	1	....	....	....	....	..	1	......	......	"	1	......	1	
October	....	1	....	....	1	....	....	2	......	......	......	"	2	......	2	
Novemb'r	....	1	....	1	....	....	....	1	1	......	......	"	1	1	2	
December	....	....	1	....	....	....	....	..	1	......	......	"	1	......	1	
Total, 1870	0	2	3	1	1	0	0	4	3	0	0		6	1	7	
1871.																
January	....	2	....	....	....	....	....	1	1	......	......	D. C.	2	......	2	1860.95
February	....	1	1	....	....	....	....	1	1	......	......	"	2	......	2	
April	....	....	1	1	....	....	....	1	1	......	......	"	2	......	2	
August	....	....	1	....	....	....	....	..	1	......	......	"	1	......	1	
October	....	1	....	1	1	....	....	..	2	1	......	D.C.&V.	2	1	3	
Novemb'r	....	4	....	1	....	....	....	2	3	......	......	D. C.	4	1	5	
December	....	3	1	1	....	3	....	1	7	......	......	"	7	1	8	
Total, 1871	0	11	4	4	1	3	0	6	16	1	0		20	3	23	
1872.																
January	....	....	....	....	1	....	....	1	......	......	......	V.	......	1	1	1862.00
April	....	....	....	1	....	....	....	..	1	......	......	D. C.	......	1	1	
May	....	....	....	....	....	1	....	1	......	......	......	V.	......	1	1	
August	....	....	....	2	....	1	....	2	1	......	......	D. C.	3	......	3	
October	....	1	....	....	....	....	....	..	1	......	......	"	......	1	1	
Novemb'r	....	1	1	1	....	....	....	2	1	......	......	"	3	......	3	
December	....	1	....	....	....	....	....	1	......	......	......	"	1	......	1	
Total, 1872	0	3	1	4	1	2	0	7	4	0	0		7	4	11	

NOTE.—D. C. signifies double-headed rail. V. signifies American rail.

Recapitulation of Rails broken per year on the Auxiliary Lines of the Paris and Lyons Railway.

LINE FROM AMBERIEU TO GENEVA.*

DATES.	DESCENTS.				ASCENTS.			Straight line.	LINE WITH A RADIUS OF CURVATURE.			Form of rails.	RAILS BROKEN.		Total.	Time that the rails were placed on the road.	Gross tonnage by kilometres, of single track, and by year.
	Above 0.008.	From 0.008 to 0.005.	From 0.005 to 0.002.	From 0.002 to ascents 0.002.	From 0.002 to 0.005.	From 0.005 to 0.008.	Above 0.008.		Above 500.	From 500 to 301.	From 300 and below.		After being turned over	Before being turned over.			
1869	1	2	2	3	3	0	0	2	6	3	0	D. C.	6	5	11	1858. 46	474,272 tons.
1870	5	2	3	7	6	3	2	11	12	5	0	D.C.&V	15	13	28	1858. 97	613,315 "
1871	18	16	14	20	7	8	6	38	39	12	0	D. C.	60	29	39	1860. 34	752,358 "
1872	17	2	0	12	7	5	11	20	21	13	0	"	37	17	54	1862. 01	848,974 "

LINE FROM TARASCON TO CETTE.

1869	0	0	0	4	0	0	0	3	1	0	0	D. C.	4	0	4	1859. 00	1,620,459 tns.
1870	0	0	0	6	0	0	0	4	2	0	0	"	4	2	6	1860. 00	1,661,000 "
1871	0	0	0	5	1	0	0	4	2	0	0	D.C.&V.	3	3	6	1861. 00	1,707,000 "
1872	0	0	0	4	0	0	0	3	1	0	0	D. C.	2	2	4	1862. 00	2,051,311 "

LINE FROM ST. GERMAIN-DES-FOSSES TO BRIOUDE.

1869	0	1	1	2	0	1	0	2	2	1	0	D. C.	3	2	5	1859. 01	587,359 tons.
1870	0	2	3	1	1	0	0	4	3	0	0	"	6	1	7	1859. 91	620,000 "
1871	0	11	4	4	1	3	0	6	16	1	0	D.C.&V.	20	3	23	1860. 95	650,920 "
1872	0	3	1	4	1	2	0	7	4	0	0	D.C.&V.	7	4	11	1862. 00	681,748 "

* As the road is composed of two tracks each rail supports only half the tonnage.

The following table shows the relative proportions of the different iron and steel rails laid down on these lines, and the relative proportions of iron rails broken in the four cold months, as compared with the eight others. It is remarkable to see, in this table, how much better the American rail resists than the double-headed.

The line from Amberieu to Geneva has in plan no curve with a radius inferior to 400 m., and in profile it has no elevation which exceeds 0.013. This line, therefore, represents the mean of the lines of large curves and small inclinations, and lines of large curves and great inclination.

It is traversed by two expresses daily, that of Geneva and that of Italy, which go at the rate of 50 to 55 km. per hour, and frequently at as high a speed as 75 to 82 km. The traffic is very great. Throughout the length of this line there is a very great variation in temperature in the different seasons. In summer, the temperature is 35° C. = 95° F., and the greatest cold of winter is —18° C. = 0° F.

Proportion between the Iron Rails broken and those laid on the Auxiliary Lines of the Lyons Railroad.

LINE FROM AMBERIEU TO GENEVA.

DATES.	Length of Single Track.				Length of rails respectively.		Number of rails.		Number of rails broken.				Proportion for 100,000.			
	Steel rails.	V. Iron rails.	D. C. Iron rails.	Total.	V.	D. C.	V.	D. C.	In Jan., Feb., Nov., and Dec.		For the other months.		In Jan., Feb., Nov., and Dec.		For the other months.	
									V.	D. C.	V.	D. C.	V.	D. C.	V.	D. C.
	kilometres.	kilometres.	kilometres.	kilom.	kilom.	kilom.										
1869	....	7.354	222.176	229.530	14.708	444.352	2,451	74,058	....	5	....	6	....	6.75	....	8.10
1870	....	18.837	210.693	" "	37.674	421 386	6,279	70,231	....	21	....	7	....	29.90	....	9.96
1871	....	45.887	183.643	" "	91.774	367.286	15,296	61,214	....	67	....	22	....	109.45	....	35.94
1872	15.655	63.225	150.650	" "	126.450	301.300	21,075	50,217	....	32	....	22	....	63.60	....	43.81
LINE FROM TARASCON TO CETTE.																
1869	0.168	155 345	46.799	202.312	310.690	93.598	51,782	19,500	....	4	....	....	....	20.51	....	....
1870	6.689	161.860	33.763	" "	323.720	67.256	53,953	14,068	....	4	....	2	....	28.43	....	14.22
1871	8.231	171.082	22.999	" "	342.164	45.998	57,027	9,583	1	3	2	....	1.75	31.31	3.50	....
1872	21.190	171.486	9.636	" "	342.972	19.272	57,162	4,015	1	1	1	1	1.75	24.90	1.75	....
LINE FROM ST. GERMAIN-DES-FOSSES TO BRIOUDE.																
1869	....	23.840	181.752	205.592	47.680	363.504	7,947	66,092	....	4	....	1	....	6.05	....	1.51
1870	....	37.706	167.886	" "	75.412	335.772	12,569	61,049	....	4	....	3	....	6.55	....	4.91
1871	....	57.472	148.120	" "	114.944	296.240	19,157	53,862	....	17	1	5	....	31.56	5.22	9.28
1872	....	61.893	143.699	" "	123.786	287.398	20,631	52,254	1	4	1	5	4.84	7.65	4.84	9.56

The *fracture* of iron rails only is given in this table.

The line from Tarascon to Cette is one of the lines of large curves and small inclinations. The speed is the same as for the Geneva line, but the quick trains are heavier. The traffic is great, though not as great as on the Geneva line. The temperature is rather hot than otherwise, and there is no very great amount of cold.

The line from St. Germain-des-Fosses to Brioude has a great many curves, a very large number of which have a radius inferior to 400 m., several of them below 300 m. The maximum inclination is not over 0.010. The least speed is generally 40 km. the hour, and the greatest is accidentally 60 km. The traffic is less than that upon the previous line; but about the same as that of the Geneva line. The temperature varies from 35° C. = 95° F. to —10° C. = 14° F.

It will be seen by the table given below that on the Geneva line, where the greatest cold occurs, by far the greater portion of the rails were broken, during the four years, in the months of January, February, and December; that on the St. Germain line, where the next lowest temperature occurs, they were broken in November and December; while on the line where the temperature is about equal, they were broken in January and December; or, in general, that the cold months are those in which the greatest number of fractures occur.

Recapitulation of the number of Rails broken per month on the Auxiliary Lines of the Lyons Railroad.

	Amberieu to Geneva.				Total.	Tarascon to Cette.				Total.	St. Germain-des-Fosses to Brioude.				Total.
	1869	1870	1871	1872		1869	1870	1871	1872		1869	1870	1871	1872	
January..	1	4	38	11	54	....	1	2	1	4	1	....	2	1	4
February.	1	3	12	6	22	1	1	1	...	3	1	1	2	....	4
March......	3	2	10	5	20	....	1	....	2	3	......	....	....	....	......
April.......	......		3	4	8	....	....	....	....	......	......	1	2	1	4
May..........	......		2	....	2	....	....	....	....	......	......	....	....	1	1
June........	......	1	......	2	3	....	....	1	....	1	......	....	....	....	......
July..........	1	......	1	3	5	....	1	....	....	1	.....	....	....	....	......
August....	1	1	4	2	8	....	....	....	....	......	......	....	1	3	4
Septemb'r	1	1	1	4	7	....	....	....	....	......	......	....	....	....	......
October....	......	1	1	2	4	....	....	1	....	1	1	2	3	1	7
Novemb'r	1	5	6	5	17	2	....	1	....	3	1	2	5	3	11
December	2	9	11	10	32	1	2	....	1	4	1	1	8	1	11

The same results are shown by the statistics which were collected for me by the Orleans Company for the years 1864 to 1872, which show as to the mean of all the years, that the greatest number of rails broken was in January, and that about the same number were broken in the months of February and December, March and November, and April and October. It then seems to increase in May, to diminish in June, to increase in July, then suddenly to fall in August, to gradually increase again to its maximum in January.

Iron Rails broken, per month, on the Principal Roads on the Lines of the Orleans Company of France during the years 1864 *to* 1872:

Years.	Lengths of the principal lines. Kilom.	Number of Rails broken during the months of												Total.	Proportion of rails broken to the 100 kilometres of road.
		January.	Februa'y	March.	April.	May.	June.	July.	August.	Sept.	October.	Nov.	Dec.		
1864	3,343	113	94	72	61	58	45	45	50	53	54	98	77	820	21.3
1865	4,016	123	116	111	79	49	42	24	33	25	60	83	99	844	21.0
1866	4,265	110	86	91	74	66	52	51	50	48	95	101	125	949	22.2
1867	4,538	151	109	111	102	80	77	60	63	59	88	84	121	1,105	24.3
1868	4,796	153	126	126	96	57	35	38	56	45	62	78	98	970	20.2
1869	5,018	105	97	101	80	65	54	50	41	54	77	98	127	949	18.9
1870	5,241	123	132	96	72	62	32	37	34	35	69	130	104	926	17.6
1871	5,297	226	128	145	92	52	83	54	61	73	139	176	161	1,390	26.2
1872	5,380	248	169	166	102	91	61	46	48	47	88	127	140	1,333	24.7
Mean.	4,710	150	118	113	84	65	54	45	48	49	81	108	117	1,032	21.9

The following statistics were collected, at my request, with reference to two double-headed iron rails, No. 1 and No. 2, which were broken on the Lyons Railroad, sections of which were prepared for etching and were to have been examined. They are exceedingly interesting, as No. 1 shows an unusual life, though not so great as the life of some of the Belgian rails cited further on. The tonnage passed over it, however, was not equal to that required by the Northern Railroad for the best iron rails. No. 2 did not last so long as No. 1, but still much longer than the ordinary iron rail. The amount of tonnage which passed over it is very small. Rail No. 1 was 13 cm. high, 6 cm. in its widest part, and 20 mm. in the body of the rail. It weighed 37.50 kgs. per m. It was made at St. Jacques, Montluçon, was laid in December, 1862, and was broken January 12th, 1874. It was therefore 11 years and some days old. It was placed upon a straight line with an incline of 0.004.

The total amount of tonnage which passed over it, was 16,761,677 tons, as is shown year by year in the following table:

Rail No. 1.

Year.	Tons.	Year.	Tons.
1863,	1,515,680	1869,	1,665,115
1864,	1,418,820	1870,	768,658
1865,	1,357,650	1871,	1,767,651
1866,	1,368,210	1872,	1,856,831
1867,	1,436,785	1873,	1,952,948
1868,	1,547,673	1874,	125,676
	8,644,818	Total,	16,761,677

Rail No. 2 was 13.24 cm. high, 6 cm. in its widest part, and 18 mm. in the body of the rail, and weighed 36 kg. the metre. It was made at Fouchanbault, in March, 1868, and broken in July, 1873, after having been five years and two months in use. It was on a straight line with an incline 0.003, and the total tonnage which passed over it was 2,647,433 tons, as is shown year by year in the following table:

Rail No. 2.

Year.	Tons.	Year.	Tons.
1868, ...	338,407	1872, ...	480,583
1869, ...	531,952	1873, ...	262,695
1870, ...	527,050		———
1871, ...	506,746	Total, ...	2,647,433

The Central Railroad of Belgium, is 591 kms. in length, and uses six different kinds of rails, whose weight, and the number of kilometres used of each, is given in the table below.

Kind of rail.	Weight per metre.	Lengths laid down in kilometres.
Double-headed, with each head alike, . .	37	18
" " " " " " . .	33	153
" " " heads of different size,	34	89
American rail, ...	37	252
" "	35	76
" "	17	3

Besides this there are 141 kilometres, not included in the above, on side tracks and switches. It is found every year, as will be seen by the table, that the quality, or rather the power of resistance of iron rails decreases, which may be due in part to increase in traffic. On this road the iron rails are usually guaranteed for three years. There were, consequently, in 1870, the rails furnished by the contracts of 1867-68-69 to be examined. The following table gives the result of this examination of the rails, made for the year 1870:

Year the rail was finished.	Years of wear.	Rails rejected on Contract No. 1.	Rails rejected on Contract No. 2.	Rails rejected on Contract No. 3.	Mean for the year.
1867	3	*10.63 per ct	*31.22 per ct.	. . . . .	13.89 per ct.
1868	2	†31.26 "	*42 28 "	. . . . .	34.39 "
1869	1	*2.76 "	*3.33 "	‡0.89	2.88 "

* Hammered. † Rolled ‡ Steel

The contract No. 3, for the year 1869, was for Bessemer steel rails, which are guaranteed for seven years, and had six years yet to run. It shows an exceedingly small proportion of rejected rails. The contracts No. 1 and 2, for all the years, were for iron rails. The guarantee for iron rails is for three years, but in order to ascertain exactly how the rails wear out, the revision is made every year, and kept up each year after the term of guarantee expires. The following table gives the results of the revision of iron rails made in 1870, for each year from 1865 to 1869:

Situation of Iron Rails, guaranteed for three years, on the Grand Central Railway of Belgium, in the year 1869.

Year the rail was laid.	Number of years of service.	Percentage of rails taken up.	Percentage of rails damaged.	Total percentage of rails taken up or damaged.	Percentage of good rails remaining upon the road.
1865	5	58.92	18.62	77.54	22.46
1866	4	43.99	20.79	64.78	35.22
1867	3	2.55	11.34	13.87	86.11
1868	2	6.15	28.24	34.39	65.61
1869	1	0.29	2.59	2.88	97.12

Comparing these figures with those found as a result of the revision of 1869, the following result was found for the year 1870:

Situation of Iron Rails, guaranteed for three years, on the Grand Central Railway of Belgium, in the year 1870.

Year the rail was laid.	Number of years of service.	Percentage of rails taken up.	Percentage of rails damaged.	Total percentage of rails taken up or damaged.	Percentage of good rails remaining upon the road.
1865	6	17.77	8.25	26.02	73.98
1866	5	36.20	6.66	42.86	57.14
1867	4	1.88	8.61	10.49	89.51
1868	3	5.00	17.58	22.58	77.42

The revision of the rails laid down in 1867, at the expiration of the three years' guarantee, gave very different results for the two works which furnished the iron rails, as is seen by the table, the one giving a loss of 31.22 per cent., and the others a loss of 10.63 per cent. The first of these are rails which were rolled, while the others were hammered. Of the 10.63 per cent. rejected of the hammered rails, there were only 1.37 per cent. which required to be removed from the road-bed. The other 9.26 per cent., although rejected, did not need to be taken up. They can still be used for a long time on the road. The greatest confidence in these hammered iron rails is expressed by the Belgian engineers, as being far superior to any of those which are rolled.

Of those which were laid upon metallic ties, at the end of three years' service, there were only 2.49 per cent. rejected, and not a single one of these was taken off the road. Of those which were laid upon ordinary ties of wood, there were 12.44 per cent. rejected, of which 1.76 per cent. had to be taken off the road altogether. As these rails are placed in positions which are identical, and were made by the same works, the difference in wear can only be attributed to the greater stability of the road-bed due to the use of metallic ties.

The results of the examination of the rails laid in 1868, after being down two years, are very bad, but this was expected, as they showed very bad wear, after one year's use, resulting from very defective manufacture. This defect having been remedied, the hammered rails for 1869 showed only 2.76 per cent., and 3.33 per cent. rejected, or for the year only 3 per cent.; of which only 0.30 per cent. were removed from the road-bed. Whatever may be said in favor of these hammered rails, they are not to be compared with Bessemer steel rails, which after one year of use showed only 0.89 per cent. of rejected rails, not one of which had to be taken up. It will also be seen by the tables, that the number of rails taken up relatively to those which are damaged, increases very rapidly from year to year. Thus after one year, about 10 per cent.; after two years, 18 per cent.; after three years, 18 per cent.; after four years, 19 per cent.; and after five years, 79 per cent. of the damaged rails remaining on the road were taken up. It will be seen by these tables, that there remained upon the road-bed, in 1870, only 22 to 35 per cent. of the rails laid down in 1865 and 1866, that is to say, that the life of these iron rails was only four or five years. These facts, taken in connection with the results shown in all the comparative tests between iron and steel rails, seem to show that it is extravagant to use iron rails under any conditions.

The Belgian engineers speak in the highest terms of metallic ties, and were making a great many experiments upon the subject, the results of which have not reached me. They were tried extensively in Germany, and I was informed by the engineers at Krupp's works that they had definitely abandoned the use of wooden ties. I noticed, in 1873, that some of the German roads near the French frontier, which had commenced to use them, had taken them up, but I could not ascertain the cause.

I am indebted to Mr. G. Schorn, Government Engineer of Mines t Liège, Belgium, for the following statistics with regard to the life f iron rails on the state railways of Belgium, for the year 1869. hese statistics are particularly interesting, since they give not only he life of the rails but the total amount of passenger and freight raffic over the road for the year. It is, however, always a vicious ractice, to give the life of a rail in years, for this does not necessarily ignify anything, for it is evident that a rail may be laid in some art of the road where there is not much traffic, and consequently nay last indefinitely. The only proper way to express the life of a ail, is by the number of tons traffic which has passed over it.

The rails which are used on the state railways of Belgium are of ive kinds; two kinds of T-rails, two kinds of double-headed rails, nd the ordinary American rail. The T-rails are of iron, and have he stem below the head, either undulated or straight, and are laid n cast-iron chairs, which support nearly the whole of the vertical art of the T. · These T-rails were the first kind of rails ever nanufactured, and as they were made at a time when cheap rails vere not so much sought for as now, it is not at all surprising to see hat they have a life which no rail made in modern times has ever et attained, though it is quite probable that the steel rails will outast them. Such rails as these were formerly used in this country, nd have given results quite similar to these which are given abroad.

The double-headed rails are either symmetrical, or not symmetical. The fifth kind of rail is of the ordinary American pattern, vhich they had commenced to use eight years previous. These ails are laid upon ties which are 0.90 m. apart, that is to say, there re 1760 ties for an English mile, instead of 2640 ties, as is comnonly the case in the United States.

The following table gives the weight, per metre, of these different ails:

Veight, per metre, of the Different Rails used on the State Railways of Belgium, in 1869.

T-rails with a curved stem,	19 to 22 kil.
T-rails with a straight stem,	25 to 27 "
Double-headed rails with symmetrical heads,	38.5 "
Double-headed rails with dissimilar heads,	34 "
Ordinary American rail,	37 "

The following table gives the number of passengers, first, second, nd third class, carried by express, ordinary, and special trains over he road, showing a total traffic, over a road 863 km. in length, of 3,500,000 passengers:

Passenger Traffic on the State Railways of Belgium for the year 1869. *Total Length of the Road,* 862,666 *km.*

Number of Passengers Carried during the Year.

By Express trains,	First class,	383,749	1,407,881
	Second class,	353,841	
	Third class,	670,291	
By Ordinary trains,	First class,	554,681	11,803,682
	Second class,	1,564,238	
	Third class,	9,684,759	
By Special trains,	Children,	135,495	365,453
	Soldiers,	109,598	
	Civilians,	120,365	
			13,577,016

The following table gives the total quantity of freight carried over the same road, for the same year:

Quantity of Freight carried during the year 1869, *on the State Railways of Belgium.*

First class,	382,790 tons.
Second class,	414,280 "
Third class,	546,296 "
Fourth class,	1,724,911 "
Special freight,	780,037 "
Freight transported at a reduced price,	95,103 "
Freight by contract,	78,000 "
Total,	4,021,417 "
Smallest quantity sent at any one time,	103,172 "

The following table shows the entire distance, in kilometres, which every kind of train traversed:

Distance traversed by every Class of Trains during the year 1869, *on the State Railways of Belgium.*

Passenger trains,	Ordinary,	3,880,866 km.	5,069,001
	Express,	1,145,010 "	
	Special,	43,125 "	
Freight trains,	Special,	295,946 "	4,569,976
	Ordinary,	4,274,080 "	
	Total,		9,638,977

[he following table gives the number of kilometres of traffic, ich the rails, taken up from the road, supported. It is very in- sting to notice, in this table, that the service of the rail gradually reases up to thirteen years, and then gradually diminishes, until mounts to almost nothing; but even this life of thirteen years is st extraordinary for an iron rail, even though the amount of ser- e, during this time, should not have been so very high. The nber of tons carried over each rail is wanting. It is, however, essary for the proper interpretation of the table, although sup- ing the service of the rails to have been the same in all cases, as indoubtedly was, a relative view of the life of the rails is shown t:

ar of Rails taken up from the State Railways of Belgium in 1869.

ıber of years of service.	Length of rails in metres.	Number of years of service.	Length of rails in metres.
½	1,363	16	233,037
1	4,417	17	299,185
2	11,128	18	205,542
3	9,703	19	144,302
4	29,397	20	75,007
5	67,803	21	40,454
6	125,278	22	17,668
7	95,051	23	23,432
8	120,999	24	21,050
9	143,272	25	8,697
10	171,638	26	5,709
11	354,804	27	3,384
12	403,159	28	3,653
13	496,419	29	1,401
14	417,292	30	919
15	333,261	31	1,194
	Total, ...		3,870,518

[he following table gives the service already rendered by the s remaining upon the road. The increase is much less regular n in the previous table, although it is very noticeable, that after rteen years it diminished, though not so regularly as in the former e.

Wear of the Rails remaining on the State Railways of Belgium in 1869.

Number of years of service.	Length of rails in metres.	Number of years of service.	Length of rails in metres.
½	297,224	16	56,270
1	288,834	17	65,764
2	621,404	18	8,982
3	491,198	19	5,234
4	233,933	20	87,991
5	176,004	21	8,134
6	196,380	22	213
7	232,924	23	29,266
8	196,908	24	1,000
9	157,539	25	820
10	143,842	26	815
11	120,027	27	8,262
12	204,048	28	1,121
13	465,107	29	1,121
14	219,365	30	1,744
15	98,795	31	10,009
Total, ...			4,378,607

The following table gives the mean life of the rails taken up from the road, and shows the very remarkable result, that the old-fashioned T-rail and the double-headed rails, with unequal heads, have a life of 13 years. This applies, however, to rails manufactured when quality was more sought for than quantity, and we see immediately in the modern rails a diminution in life of from ½ to ⅔. The same superiority in the American rail being remarked that has been noticed elsewhere:

Mean Life of Rails taken up from the State Railways of Belgium, in the year 1869.

	Years.	
T-rails with a curved stem, ...	13	Mean life, the length of each particular kind of rail being taken into consideration, 13⅓.
T-rails with a straight stem, ...	13⅔	
Double-headed rails with dissimilar heads, . .	13⅕	
Double-headed rails with symmetrical heads, .	4⅓	
Ordinary American rails, ...	$6\frac{9}{11}$	

The following table gives the life of the rails remaining upon the road in the year 1869, and gives the same extraordinary results for the T-rails, and shows the great economy of making a first-rate article. For the first-class these rails have attained the extraordinary life of 23¼ years.

Life of the Rails remaining on the State Railways of Belgium, in 1869.

	Years.	
T-rails with a curved stem,	$23\frac{1}{4}$	Mean life, the length of each particular kind of rail being taken into consideration, $\frac{7}{10}$.
T-rails with a straight stem,	$20\frac{9}{10}$	
Double-headed rails with dissimilar heads,	$7\frac{1}{4}$	
Double-headed rails with symmetrical heads,	$4\frac{5}{7}$	
Ordinary American rail,	$3\frac{7}{9}$	

I was particularly struck with the importance attached in France, to having no repairs of any kind done to the rails by the manufacturer. The conditions of the contract are such that it is contrary to his interest to make them, or to attempt to conceal in any way any defects. I had seen so much of this kind of repair done in Germany and elsewhere, but particularly in Germany, that this condition attracted my special attention. In one of the German works, the engineer who accompanied me, pointed out with special pride the skill with which they were able to putty up defects, and stated to me that the composition and method of doing it was a secret, and that special workmen only could do it. The defects were certainly thoroughly concealed, and it required very close inspection to discover cracks which had been cut out with a hammer and chisel, or with a file, and filled up with the composition, and there was very little probability that they would be discovered, even if they were sought for in the inspection. But it is very much like trying to cure the symptoms without attacking the disease. In other works, both in this country and in Europe, no attempt whatever is made to conceal, nor apparently to prevent, these defects, and I have seen very large piles of rails ready for delivery, not a single one of which, so far as I could discover, was without what appeared to be serious defects in the flange. These rails were besides cut, punched, and nicked, cold. I do not know where they were laid, but I was quite prepared to hear from a large railway house that the life of certain rails, which laid on an ordinary road-bed without accidents or unusual wear, did not exceed 18 months.

Almost all the companies in Europe have rail repair shops for iron rails, and very ingenious machinery, which is usually copied from American works, and often conducted by Americans. In these works, defective rails removed from the road-bed are repaired. It is evident that the companies have a great advantage in doing this, since in most cases, rails which are only damaged, remain the property of the company, but must be paid for by the manufacturer, under the stipulations agreed upon in the contract. These repairs usually consist in putting in pieces, to fill out the rail where it has been damaged. In most cases these pieces are put into the head at the ends of the rail, but they sometimes require to be put in the head in the middle of the rail, and occasionally any other parts are replaced in the same way. The furnaces used for doing this work are so constructed, that the rail may be heated in any part independently of the other. The pieces to be put in are fastened with strong wire to the rail, which is then heated at that point, and passed through rolls so adjusted, that they may bear only on the point heated. This requires very great skill in the workmen, much more skill than time. When the ends are pierced, the pile is arranged in such a way as to make the rail too long, and it is afterwards cut to length, in order to have a perfect end. When the rails are not badly damaged, and are properly repaired, they look well, and can be very profitably used on turnouts or any other part of the road where they are not exposed to very great wear. Steel rails are never repaired, for the only accidents that ever happen to them is breakage, and then they are replaced by the manufacturer.

Steel rails have, of late years, been very generally adopted by the leading companies of this country and Europe. The fears expressed with regard to their not being able to resist the influence of the climate of this country, have proved to have been entirely groundless. The Central Railroad of Belgium commenced to use them in 1869, in the part of their road where *no* iron rails stood the test, with the most satisfactory results. It was at first feared that the steel rails would become rapidly polished, and that the locomotive would, consequently, have less adherence, and that the brakes would necessarily act less perfectly; but all these fears were proved to be without foundation, though steel rails do certainly become polished much more rapidly than iron.

The Northern Railway of France adopted, in 1873, a steel rail of the American pattern, which weighed 30 kgs. per m., made at Terrenoire and at Creusot. The normal length of this rail is 8 m., but in order to facilitate the manufacture lengths of 5, 6, and 7 m., are also admitted. The strength of this rail, in comparison with the types of all the rails in use on the principal roads of Europe, is shown in the table below. The limit of force exercised on the fibres of the top of the head of the steel rail, of 30 kgs., and the iron one of 37 kgs., when new, are represented for the steel rails by $\frac{V}{I} = 7.742$, and for the iron by $\frac{V'}{I'} = 7.012$. The ratio of these two values is $\frac{7.742}{7.012} = 1.104$. For the base of the foot, the forces are 7981 for steel and 6472 for iron, whose ratio is $\frac{7.981}{6.472} = 1.233$.

If these same forces are calculated for the steel rail nearly worn out, and the new iron rail, the ratios are found to be $\frac{9689}{7012} = 1882$ for the head, and $\frac{9100}{6472} = 1406$ for the foot. For the new rail the greatest increase of force is less than 0.25 of the primitive values, and for the steel rail worn as far as it can be used, the greatest increase of the interior force, with regard to those of a new iron rail, is less than the 0.041th part of the primitive values. The limits of elasticity of steel are, however, double that of iron, so that the steel rail which is worn out, or has arrived at the limit of greatest wear, is still stronger than a new iron rail. These figures apply to the charge supposed to be at rest on the rails. If the charge is supposed in motion, it is found that the forces are increased only 0.264 for new steel rails, while for iron rails they are increased 0.301, and that when the steel rail has arrived at its maximum use, it is only 0.34; so that, notwithstanding its light weight, the steel is better than the iron rail. For the resistance to friction it is found that if T represents the force tending to cut it, $s = 743$ T for the steel rail of 30 kg. and $s = 662$ T for the iron. This increase is, however, fully compensated by the increased resistance of the steel, as the increased strain does not exceed, in effective force, more than 5 kg. per square millimetre.

Investigations, made by the Northern Railroad of France, with regard to the life of steel rails, show that the period, though very variable, unlike iron rails, depends directly upon the amount of weight carried over them. It has been ascertained that the steel rails wear out slowly in parallel layers, while iron rails deteriorate very rapidly, and are worn out before they have lost any very great amount of their weight by wear. In order to ascertain exactly what the wear is, a cast in plaster of the rail before it is laid down is taken, and after a certain number of million tons have passed over it, it is taken up and another cast is taken. The difference is then measured and gives the wear of the rail, per million tons, in millimetres. It has been found, after some years of experiment, that the *very best* iron rails do not last on this line for a circulation of over 20,000,000 tons, while *ordinary* iron rails will not last for over 14,000,000. All the experiments, however, show that steel rails wear uniformly a millimetre for a circulation of 20,000,000 tons, and as the rails now in use are calculated for a wear of 10 millimetres, we can suppose, accidents being left out of consideration, that the steel rail will not wear out before 200,000,000 tons have passed over it, that is to say, that the ordinary steel rail is ten times better than the best iron rail.

The temperature at which the steel rails are finished, has, of course, a great deal to do with its strength, and consequently with its life, and too little attention has been given to this subject. A great many experiments made with the object of comparing the two kinds of rails have shown, that in all the experiments on pressure, iron rails preserve a very appreciable permanent set, as soon as the compression attains 17 or 18 kgs. per square mm., while in steel rails this deformation does not commence until about 38 kgs. In the experiments upon direct traction, iron rails of good quality have a resistance of between 28 and 36 kgs. per square mm. Steel rails have a resistance between 65 and 70.

In the experiments upon shock, iron rails do not resist a force greater than 400 kilogrammetres, while for steel rails this resistance is about 900 km. Another great advantage of steel over iron rails is, that as they are made of a homogeneous material, when they are worn out, they are worth the full value of the steel contained, as steel to be remelted, while the iron of old rails not being homogeneous, but being composed of materials which are essentially different, more especially when the head has been made of iron containing phosphorus, is worth but little. The conditions of the contracts however, are generally such as to preclude the use of old iron rails, in any quantity, in the packages for the new ones.

The substitution of steel rails for iron, in France, has corresponded at once to a very considerable economy in the care of the road, at the same time that it gives greater resistance and security. For all these reasons the Northern Railway of France has adopted the steel rail of 30 k.*

These rails are not only stronger and better, but are actually cheaper, metre for metre, than the old iron ones of 37 kg. were, as shown by the table on the next page.

It is more than probable that the same results will hold good elsewhere. In this country, such a result would diminish the expenses for repair of the road, by increasing the life of the rails, so as in some cases to make it possible to run roads, now working

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* This rail is made heavier than the steel rail usually adopted in the United States, which is 27 k. In Turkey for the main lines they use a steel rail of 25 k.

Comparison of the cost price of a kilometre of road laid with Iron Rails of 37 kilogrammes, and of Steel Rails of 30 kilogrammes.

	Iron rails of 37 kilogrammes.			Steel rails of 30 kilogrammes.		
	Quantities	Price.	Cost.	Quantities	Price.	Cost.
	Tons.	Francs.	Francs.	Tons.	Francs.	Francs.
Rails, ...	74.	350	25,900.	60.	420	25,200
Fish-plates, ...	8.20	350	1,120.	2.325	350	813.75
Bolts, ...	.562	530	297.86	.420	580	222.60
Screws, ...	1.685	650	1,095.25	1.580	650	1,027.
Wedges for rail ends, .	.032	578	18.50	.024	578	13.87
Ties, ...	1.167	5	5,835.	1.125	5	5,625.
Care of the road, transportation, cost of storage, which is 35 francs the ton of iron or for	79.479	35	2,781.76	64.349	35	2.252.21
Cost of a kilometre of single track, . . .	. . . .	. . .	37,048.37	. . . .	. . .	35,154.48
Excess of the cost of iron over the steel, per kilometre, ...	. . . .	. . .	. . . . .	. . . .	. . .	1,893.94
Or per metre in round numbers, ...	. . . .	. . .	. . . . .	. . . .	. . .	1.90

either without profit, or at a loss, and it is very desirable that statistics should be collected on this subject.

In changing the weight of the steel rail on the Northern Railroad it was necessary to take into account, that there were a large number of old iron rails still in use upon the road, and it was therefore desirable to make the steel rail of 30 k. of the same height as the old iron rail which weighed 37 k. Taking this as a starting-point, it was necessary to make the head of the rail as large as possible, and to reduce its body and the width of the foot as much as would be safe, in order to have the greatest amount of material in the head, as upon the depth of this part of the rail, other things being equal, its life depends, since steel rails wear out proportionately to the amount of traffic. That this has been done wisely, is shown by the wear of the rail on the road, and by the following table prepared by the Northern Railroad for the purpose of instituting a comparison between the rails of this road and those in use upon all the principal roads of Europe. It shows a number of very interesting comparative results.

The steel rail of 30 kgs. adopted by the Northern Railroad, is supported at 9 points. Near its joints the supports are 60 cm. apart, next to these 90 cm., and at all other places one metre. They are all fished, the holes for which are 0.024 m. in diameter, and are

Comparison of the Size and Strength of the different Rails used on the principal roads in Europe.

Name of rail.	Width of the head in mm.	Width of the stem in mm.	Width of the foot in mm.	Total height of rail in mm.	Section.	Weight, Iron = 7,600 Steel = 7,825	I.	Distance from the top to the mean line.	Distance from the foot to the mean line.	$\frac{V}{I}$ top.	$\frac{V}{I}$ foot.	$\frac{I}{V}$ top.	Relation between height and base.
					sm.	kgs.		m.	m.				
Northern Railroad, iron rail of 37 kgs............	62	17	105	125	0.004895	37.202	0.00000927	0.065	0.060	7,012	6,472	0.000142	$\frac{125}{105}$—1.190
Northern Railroad, steel rail of 35.360 kgs..	59	14	102	125	0.004525	35.408	0.00000878	0.0652	0.0598	7,427	6,810	0.0003146	$\frac{125}{102}$—1.225
Northern Railroad, steel rail of 30.300 kgs.. ..	56	12	97	125	0.003871	30.292	0.00000795	0.0615	0.0635	7,742	7,981	0.000129	$\frac{125}{97}$—1.288
Northern Railroad, iron rail of 30 kgs.......	58	14.8	95	113	0.003990	30.324	0.00000646	0.0578	0.0552	9,249	8,832	0.000108	$\frac{113}{95}$—1.190
Lyons Railroad, steel rail, pattern P. M........	60	16	130	130	0.00511	40.	0.00001137	0.0702	0.0598	6,172	5,260	0.000162	$\frac{130}{130}$—1.000
Lyons Railroad, iron rail, pattern P. L. M...	60	16	100	130	0.00475	36.123	0.00001019	0.06604	0.06396	6,464	6,270	0.000154	$\frac{180}{100}$—1.800
Eastern Railroad, iron rail	60	15	99	120	0.004596	34.540	0.00000823	0.06205	0.05799	7,539	7,035	0.000132	$\frac{120}{99}$—1.212
Cologne, Minden Co., iron rail..	58.5	14	914	124	0.004322	32.347	0.00000850	0.0635	0.0605	7,472	7,118	0.000133	$\frac{124}{91.4}$—1.356
Southern Railr'd of Austria, with heavy grade	57	13	104	122	0.00396	steel, 31.050	0.00000840	0.0644	0.0576	7,666	6,852	0.000130	$\frac{122}{104}$—1.173
*Railroad around Vienna. Experiment.).....	53	16	99	79	0.00307	steel, 24.022	0.00000294	0.0451	0.0339	15,340	11,530	0.000065	$\frac{79}{99}$—0.798
†Northern Railroad of Austria, steel rail.......	57	13	110	120	0.003928	steel, 30.736	0.00000763	0.0636	0.0564	8,335	7,392	0.000120	$\frac{120}{110}$—1.091
‡State Austrian Railroad, steel or iron rail	62	17	105	125	....	....	....	....	....	....	....	....	$\frac{125}{105}$—1.190

* Test made upon a very small number of rails.

† This rail has been used since 1866 on Northern road of Austria.

‡ This rail differs very little from the type of 37 kgs. on the Northern Railroad.

bored. They are placed directly upon the ties, in places which are cut out for them, and are fixed by two spikes of galvanized iron for the intermediate ties, and with four for the joints. In order that the spikes shall not split the ties at the ends of the rails, they are not placed opposite to one another. Particular instructions are given, that every care shall be taken that the spikes shall not be placed in any pre-existing crack in the tie, nor in such a way, that they will interfere with spikes placed against the end of the rail. These spikes or wedges, are placed at one end of the rail, only to prevent it from slipping, leaving the other extremity free for movements of dilatation. To avoid the tendency of the rail, in all soft wood, to shove the outside spike, a cast-iron ring 2.50 cm. in thickness, with several projections on its outside diameter, is let into the tie, and the spike is driven through it, care being taken that there shall be at least 4 mm. between the upper part of the ring and the lower part of the rail. They are now trying the experiment of not placing the ends of the rails upon the same ties, but either on the next, or on a tie at some distance, so that the joint on one side of the track, will be either opposite a point near the end, or the middle of the rails on the other. The result is, that as the shocks due to the passage over the joints, are not simultaneous, their action upon the movement of the car is much less perceptible, and the road is much smoother. This method has not been long under trial, but there seems to be a considerable decrease in wear and tear.

A large series of both iron and steel rail ends, cut off near the point of fracture, collected from all the different roads, under varying circumstances, were prepared for etching, in order to study how far the fracture might have been caused by bad welding, or other defects, which entirely escape all ordinary inspection, and to ascertain whether, in the case of steel rails, there was any concentration of material, as has been suggested, near the point of fracture, which would tend to make the rail brittle at that point. Very little attention is paid to this subject of etching, in tests for iron and steel, much less than it deserves. It was hoped that important discoveries with regard to the causes of fracture of the rails would be made, that many of the points which are now not understood would be partially if not wholly explained, by the developments, either of concentrations of impurities, or physical defects, which cannot be made visible in any other way. The chemical constitution also of the rail is a subject which demands the most serious attention, more especially as it is now known that the relative proportions, more than the amount, of certain substances, influence the strength of both iron and steel. Unfortunately the panic of 1873 prevented the execution not only of the analyses of the large collections of pieces of broken rails made for the purpose, but also all the other chemical and physical experiments which had been planned, and for some of which instruments had been devised.

Investigation seems to show that the fracture of almost all the broken steel rails started in defects which escaped the observation, but which were in the rail when it was laid. These defects, if not in the rail when delivered to the company, are generally caused, to a very great extent, by the rail being thrown from the car to the ground, or by other rough handling. The cases where sound rails are broken by the trains are comparatively rare. It is very noticeable, that the percentage of steel rails broken soon after they are laid, is exceedingly small, and that, up to a certain time after they have been down, it seems to increase, and then gradually to be reduced to almost nothing. This is owing to the fact that the fissures or cracks which escape observation, require some time to be developed sufficient to cause rupture, and that this time having been reached, a large number of rails break, and then, after these causes cease to operate, the defective rails being for the most part removed, the normal wear is shown in the sound rails that remain. In rails broken within six months after they were laid, it is generally easy to see that the fracture commenced in a small flaw and propagated itself, from the fact that the crack is, more or less, rusted where the break commenced. This cannot, however, be verified in all cases, because the rail is often allowed to lie for some days beside the track, instead of being always taken up and sent immediately to the workshops, although instructions are generally given, that whenever a rail is found broken, it shall be transported at once to the nearest station, to be sent to the workshops of the headquarters of the road, to be tested.

The holes for the fish-bolts, in rails of any kind, but particularly steel rails, should never be punched, as minute fissures are likely to be developed in the circumference of the holes;* nor should they, for the same reason, be notched in the flange. It is found that a very large percentage of punched and notched rails break shortly after they have been laid. Hence all the roads stipulate that all steel rails which are to be fished, should be bored, and that on no account should any change in the condition of the rail be made, after it has once passed through the rolls, except directly at the ends. It has been ascertained, by careful examination of the facts, that careless handling of the rails is one of the most frequent ways in which the small fissures, which eventually cause their fracture, are produced, and is, consequently, one of the most fruitful causes of railway accidents. It is positively forbidden, by most of the French railways and manufacturers, ever to throw a rail down, or allow it to drop from any height. To discharge it from the car, at least two rails are required to be placed as skids, upon which the rails are to slide to the ground. They are then to be lifted to the place to which they are to go. When rails are being piled up, at the works, these skids are a great convenience to the workmen, and they are always used; but, in discharging them from cars, they are not, as it is often inconvenient to place them, and whenever the men think that they are not watched, they will discharge the rails by throwing them, but when this is discovered, it is always punished.

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* It is asserted that the fissures produced in the circumference of the holes are so short, that they can be entirely removed by subsequently reaming out the holes. This saves the expense of drilling, and is now under trial in some of the French works.

It is generally in the winter that the largest number of rails are broken, and there has been a great deal of speculation, but very few experiments with regard to the effect of cold upon the wear of iron and steel rails. I had devised a method of making such tests, and was to have made a very large series of experiments upon this subject, but unfortunately, was prevented. I am inclined to think, however, from a preliminary examination of the subject, that the cause of fracture is not so much owing to the cold—though both iron and steel have a diminished power of resistance, when subjected to great cold—as to the fact that the road-bed is entirely frozen and ridged during many months at a time. The want of elasticity in the road-bed would tend to increase any flaws that might have been started, and the shock of the passing trains would have a much greater effect upon the rail during the winter than during the summer months, when part of the shock is diminished by the elasticity of the road-bed. The road-bed is also less capable of inspection in the winter, owing to the accumulation of ice and snow, and a crack or flaw commenced, is less likely to be seen, or a broken rail is more likely to be kept in its place, for a certain time, than in summer, and is therefore less likely to be removed before an accident occurs. I am sustained in this opinion by some of the best engineers in Europe.

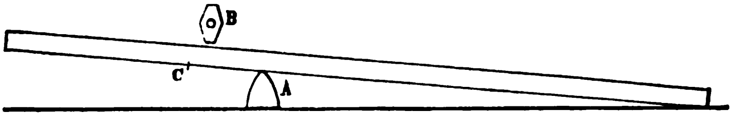
It is greatly to be wished that some such tests as I had proposed to make, should be carried out by some of our roads, in order that this point may be definitely settled, and that we may know exactly how far the strength of the rail is diminished by the cold of the winter. When this is known it is probable some remedy will be found for the greater number of accidents caused by broken rails in the winter months.

In closing this paper, I must express my warmest thanks to the Orleans and Lyons Railway Company, of France, whose engineers entered heartily into my plans of collecting statistics and specific information relating to the broken rails which were sent to me for further investigation. To the engineers of the Northern Railroad of France, who not only furnished me with a large amount of information, but allowed me to frequently use their shops without charge. I can only express to them and to the Institute my very great regret that the panic of 1873, which has so seriously affected the whole of this country, prevented the investigation from being more than fairly commenced in Europe, and did not allow of anything being done in this country.

Mr. JOHN FRITZ remarked that the fracture of steel rails was referable either to abnormal chemical composition or improper mechanical treatment. Often we have in the chemical composition alone a sufficient cause for breakage. It is known that where the amount of carbon is high, the amount of silicon and phosphorus must be low. He had, for instance, examined two foreign rails of the same make which broke in the track. One contained 0.16 per cent. carbon, 0.087 silicon, and 0.127 phosphorus; the other 0.58 carbon, 0.56 silicon, and 0.112 phosphorus. They were both forged out to small bars, and while the first could be bent double cold, the last broke at the first attempt to bend it. But more important, if possible, than the chemical composition is the mechanical treatment. All violent disturbance of the molecular arrangement of the particles of the steel when cold, as in straightening, punching, notching, etc., tends to make it brittle. Sandberg has shown that hard steel rails which were notched on the flange suffered a loss of strength of 50 to 97 per cent.—the former where the notch was semicircular, and the latter when the notch was square. At the Bethlehem Iron Works, a sample ingot is taken from each blow, forged out to a bar about ½ by 1 inch, and bent until the ends meet. From this ingot samples are also taken for analysis. A rail from each heat is further subjected to a drop test of 2000 pounds falling fifteen feet. When the rail is notched or punched, it will sometimes break with a drop of one foot. The question naturally arises, Why expend so much care on a rail that will stand the fifteen feet drop, and then deliberately reduce the strength 90 per cent. or more at each end? The advantage in favor of drilling over punching is very marked. Where a punched rail will break with a drop of one to two feet, a drilled rail will stand eight to ten. Not long since an engine on the Lehigh Valley Railroad ran off the track and struck a number of steel rails on the sides or flanges. All of these rails broke shortly after in the track. With regard to iron rails, it is simply a matter of good iron and of dollars and cents. There is no mystery here, and it is not worth discussion.

Mr. W. A. Sweet, of Syracuse, said: While I am neither a manufacturer of steel rails nor a user of them, my experience as a manipulator of rail-ends and old rails has given me great and varied experience in the breaking of rails, and has led me to conclusions perhaps different from any one present. Not having shears sufficiently strong to cut a steel rail, it has been a study with me to find a way to break old steel rails with the least physical labor. I find, by arranging the rail as shown in the accompanying sketch, where A represents the point of support, B the sledge, and C the position of the nick in the flange, the rail is almost invariably broken at the first blow. There is a perceptible time, after striking the blow, before the suspended end drops off, appearing as if a wave of vibration passed to the end and back again to the point where the flange is cut, where it seems to stop suddenly, the wave of vibration appearing to me to be arrested and concentrated to that extent that the molecular constitution of the metal is destroyed. It may be, however, that the vibrations do not go to the end and return, but are arrested in the first instance at the point where the nick or dent is made. That it is a wave of vibration that causes breaking in steel rails I am fully convinced. I do not think that the cutting or punching of the holes for the fish-plate bolts would weaken the rail beyond what would be produced by the removal of so much metal, provided that the rails

Fig. 7.



had been rolled at the proper temperature when finished. But where the ends are allowed to get loose, my opinion is that they break at the remote end, after the passage of the last wheel of the train.

I think if a rail is actually tight in the fish-plate (and but few are), there will be no breakage without the cause is on the face of it, as by the running off of the cars, or some actual duty too great for their strength to bear.

It is well known that bells are supposed to be made the proper shape to throw off vibration, and to continue to do it for years without breaking. When one is not so proportioned it soon breaks, and must be replaced by a new one, and no credit accrues to the maker of the faulty one.

In the case of a rail, we have a bar equal in size from end to end, and it only wants a mark or dent with a hammer, to arrest the waves a few times, and the result is a break. The now accepted fact, that punching the holes for the fish-plate bolts weakens the rail 75 per cent., shows, to a thinking mind, that there is something wrong, either in the molecular construction of the metal itself, or in its manipulation.

I claim, and have for years, that it is in the *manipulation;* that steel rails have not yet been rolled properly, or finished at a proper heat. They should be rolled and finished in chilled rolls, with finished passes, and at a heat that will just set the scale. Having rolled thousands of tons of rail-ends into small bars, and so treated them that they will bend double and stand pounding down flat, I feel prepared to say that, if rails were rolled as we roll tire steel, they would stand ten times the shock they now will, and that punching the holes would weaken them only in proportion to the amount of metal removed.

We are taking Bessemer steel and converting it into blister steel by the cementing process (imparting to it enough carbon, so that by analysis it shows 1 per cent.), rolling it into spring steel, and from it making hundreds of pairs of springs per day. The leaves of the same are 1¼ inches wide, with three holes, 5-16 inches in diameter, punched in each one, and when they are tested they do not break in the holes. There are many thousands of our tire for carriages, where the bolt-hole is more than ¼ the width of the tire, and a tire from this stock is scarcely ever broken. The tire is strained on the wheel in setting, as is well known, and receives many blows from contact with the pavements, fully equal to what rails are subjected to, and probably much more in proportion to the actual weight of its section.